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Education

Education can take many forms and serve many needs. The earliest of civilizations more than 3,000 years ago—in Egypt, Mesopotamia, and China—bear this out. Over time, instruction of the young, which had previously occurred through interaction with knowledgeable and skilled adults in the context of daily life, shifted to institutional settings such as royal courts and temples, each with its own standardized body of knowledge. Schools with prescribed curricula and appointed teachers were founded for various purposes: to transmit knowledge and information, societal values, and useful technical skills; to socialize individuals to particular roles; to train and select political, religious, and social leaders; and to ensure the loyalty of the populace to standing forms of governance. In Great Britain, for example, the advent of "public schools" (private, tuition-charging schools that prepared many students for public service) helped define and instill an ethos that contributed to the strength of the British Empire. Standards of behaviour, speech, and appearance were a primary product of these schools, while academic achievement was often secondary. Through this sort of social conformity, the public schools set the standards of conduct for British officials from the early 19th to the mid-20th century.

By the second half of the 19th century, the selective preparation of elite members of society had evolved into more inclusive systems of education in northern Europe, North America, and Japan. Egalitarian ideologies combined with the emerging educational philosophies of Jean-Jacques Rousseau in France, Johann Heinrich Pestalozzi in Switzerland, and Friedrich Froebel in Germany, and late in the century scholars and educators such as Mori Arinori and Fukuzawa Yukichi helped to popularize Western philosophies in Asia. Around the world, the advent of mass schooling coincided with major economic, political, and cultural transformations—many of which stemmed from industrialization.

These social and cultural changes have been a prime focus of the social sciences. From the very origins of their disciplines in the late 1800s, sociologists and anthropologists have asked what role education plays in helping human societies to reproduce themselves from one generation to the next without falling into disarray. What allows a society to adapt to its environment while retaining some historical cohesion and continuity? How does a society conserve essential features of its cultural and technological repertoire? And is education, in the words of philosopher John Dewey, a "process of accommodating the future to the past, or [a] utilization of the past for a resource in a developing future?"

This article looks at the past and present purposes and influence of education and analyzes the role education plays in this process of cultural transmission and transformation. For a detailed history of education, see the article EDUCATION, HISTORY OF, which follows this one. A further discussion of educational theory can be found in the article PHILOSOPHIES OF THE BRANCHES OF KNOWLEDGE. The teaching profession and the functions and methods of teachers are treated in TEACHING.

For coverage of related topics, see the *Propædia*, sections 561 and 562, and the Index.

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Education and society

One of the most significant phenomena of the 20th century was the dramatic expansion and extension of public (in this case meaning government-sponsored) education systems around the world: the number of schools grew, as did the number of children attending them. Similarly, the subjects taught in schools broadened from the basics of mathematics and language to include sciences and the arts.

THE DEVELOPMENT AND GROWTH OF NATIONAL EDUCATION SYSTEMS

Various explanations have been given for the substantial increase in numbers of youths as well as adults attending government-sponsored schools; social scientists tend to categorize the reasons for these enrollment increases as products of either conflict or consensus in the process of social change. In most cases, these perspectives are rooted in social science theories that were formulated in the late 19th and early 20th centuries.

Education and social cohesion. One major school of thought is represented in the work of French sociologist Émile Durkheim, who explained social phenomena from a consensus perspective. According to him, the achievement of social cohesion—exemplified in Europe's large-scale national societies as they experienced industrialization, urbanization, and the secularization of governing bodies—required a universalistic agency capable of transmitting core values to the populace. These values included a common history that contributed to cultural continuity, social rules that instilled moral discipline and a sense of responsibility for all members of the society, and occupational skills that would meet the society's complex and dynamic needs. Durkheim recognized that public schooling and teachers—as agents of a larger, moral society—served these necessary functions. As he observed in *The Rules of Sociological Method* (1895), "Education sets out precisely with the object of creating a social being."

Durkheim's thoughts, expressed near the turn of the 20th century, were reflected in the policies of newly sovereign states in the post-World War II period. Upon achieving

their independence, governments throughout Africa and Asia quickly established systems of public instruction that sought to help achieve a sense of national identity in societies historically divided by tribal, ethnic, linguistic, religious, and geographic differences.

Education and social conflict. Political theorist and revolutionary Karl Marx viewed public schooling as a form of ideological control imposed by dominant groups. This perspective saw education not as building social cohesion but as reproducing a division of labour or enabling various status groups to gain control of organizations and to influence the distribution of valued resources. German sociologist Max Weber regarded educational credentials as one such resource, in that credentials function as a form of "cultural capital" that can generally preserve the status quo while granting social mobility to select members of society.

Education and personal growth. The American philosopher John Dewey believed that education should mean the total development of the child. On the basis of the observations he made at the University of Chicago Laboratory Schools—the experimental elementary schools that he founded in 1896—Dewey developed revolutionary educational theories that sparked the progressive education movement in the United States. As Dewey propounded in *The School and Society* (1899) and *The Child and the Curriculum* (1902), education must be tied to experience, not abstract thought, and must be built upon the interests and developmental needs of the child. He argued for a student-centred, not subject-centred, curriculum and stressed the teaching of critical thought over rote memorization.

Progressive education movement

In *Experience and Education* (1938), he criticized his zealous followers who took his theories too far, who ignored serious scholarship and organized subject matter, and who accepted mere vocational training for their students. If prudently applied, progressive education could, Dewey believed,

> shape the experiences of the young so that instead of reproducing current habits, better habits shall be formed, and thus the future adult society be an improvement on their own.

Concurrent pedagogies appeared in European institutions such as Ovide Decroly's École de l'Ermitage, which envisioned students utilizing the classroom as a workshop, and Maria Montessori's Casa dei Bambini, which incorporated experiential and tactile learning methods through students' use of "didactic materials."

Education and civil society. Toward the end of the 20th century, theories such as those represented by the consensus and conflict models were increasingly viewed as oversimplifications of social processes and in many quarters gave way to more particularized interpretations. One such perspective viewed educational expansion and extension less as a function of national interest and more as a by-product of religious, economic, political, and cultural changes that had occurred across most of Europe. Especially in the wake of the Enlightenment, an emphasis on the glorification of God was joined by the growing celebration of human progress (ultimately defined as economic growth), while concerns for the salvation of the soul were augmented by the cultivation of individual potential. As nation-states with centralized governments extended citizenship rights in the 18th century, state sponsorship of schools began to supersede the church-supported instruction that had become the norm in the 16th and 17th centuries. According to such scholars as John Meyer and Michael Hannan in *National Development and the World System: Educational, Economic, and Political Change, 1950–1970* (1979), formal systems of education not only represent the means by which nation-states have modernized and prospered economically but are also the surest route to enhancing the talents of individuals. As a requirement for all children and youths between certain ages and as an institution regulated by the state, schooling also became the primary agency for creating citizens with equal responsibilities and rights.

These values emerged in education systems worldwide, especially in the late 20th century as education professionals promoted them in developed and less-developed countries alike. As such, schools effectively carried modernity into many parts of the world, where it was met with varying degrees of resistance and acceptance. Teachers, non-governmental organizations (NGOs), and government agencies contributed, for example, to standardization in the shape and style of the classroom, types of curricula, and goals for school enrollments. In the first half of the 20th century, schools in most industrialized countries exhibited similar characteristics; that is, schools could be identified as schools. By the second half of the 20th century, these traits had become prominent in most schools around the world.

Standardized schools

Education and economic development. One explanation for the changes evidenced in this "institutionalist" view of education can be found in the human capital theory first popularized by American economist Theodore Schultz in "Investment in Human Capital," his presidential address to the American Economic Association in 1960. According to this theory, education is not a form of consumption that represents a costly expenditure for government but instead serves as an investment that improves the economic worth of individuals (*e.g.*, human capital) and thereby raises a country's overall productivity and economic competitiveness. In other words, governments support education because it ultimately strengthens their countries.

GLOBAL ENROLLMENT TRENDS

Each of these theories partially explains the widespread increase in enrollments, as reported by UNESCO, in all levels of education during the last half of the 20th century. Broadly speaking, enrollments increased substantially for school-age children and youths, while adult illiteracy rates decreased significantly. Between 1950 and 1997, worldwide gross education enrollment at all levels increased from less than half to approximately two-thirds of the relevant age-groups.

Much of this enrollment growth was a product of political change. Most countries in a postcolonial phase expand their education systems, largely because it is something governments can do at a reasonable cost with significant effect. With the opening of schools to many who were once denied education under semifeudal, colonial, or totalitarian systems, it has not been uncommon to find large numbers of average students enrolled. First-grade classes might have an age range from 6 to 11. In overall numbers primary-school enrollments between 1950 and 1997 more than tripled, from about 210 million to 668 million; secondary education increased more than 9-fold, from 41 million to 398 million; and tertiary education increased more than 12-fold, from about 7 million to 88 million. Higher levels of enrollment are usually sustained, in part because "credentialing"—the attainment of degrees or certificates of achievement—has become a social necessity. Employers tend to seek highly schooled individuals while depending on the education system to prepare and distinguish job candidates. In addition, enrollments have been known to gain momentum through the "queuing" effect; that is, when people line up to participate in something, others soon join the crowd in the belief that something of value will be obtained.

The value of credentials

Primary-level school enrollments. In not only the industrially developed world but other regions as well (Latin America, East and South Asia), gross primary-school enrollment rates had reached 95 to 100 percent by the beginning of the 21st century, while in Africa they had achieved an average of 81 percent. Some of the world's least-developed countries took the most dramatic steps toward offering universal primary education in the final decades of the 20th century. As late as 1970, less than half of the relevant school-age population attended primary schools in such countries, but by 1997 primary-school enrollments in the least-developed countries had grown to include 71.5 percent of school-age children. Some countries, however, continued to lag behind this trend, with low enrollment rates persisting in countries such as Burkina Faso (44 percent), Niger (40 percent), and Djibouti (40 percent). Primary education, as compared with higher levels of schooling, is the least costly to maintain and the easiest to expand. The challenge is to provide continuing education opportunities for those who complete basic schooling.

Secondary-level school enrollments. During the period 1950 to 1997, secondary-school enrollments worldwide expanded from less than one-fifth to almost two-thirds of the relevant age-group. Secondary education in developed countries has become, with few exceptions, universally available. In East Asia, the Arab states, and Latin America, secondary-education enrollment rates ranged from approximately 60 percent to 70 percent at the beginning of the 21st century. South Asia and Africa had the lowest enrollment rates. Enrollment numbers are somewhat dependent upon a nation's economic resources; it has been the case, for instance, that many youths cannot attend school because they are needed to supplement family income.

There was a marked worldwide trend toward more comprehensive secondary education in the second half of the 20th century. The higher enrollments were intended to permit students to continue with higher education instead of being "tracked" into different schools and programs that provided a terminal vocational education. However, increasingly large numbers of underemployed tertiary-level graduates have led to a renewed interest in vocational education. At both the primary- and secondary-education levels, another worldwide trend has been the inclusion of a greater number of courses in mathematics and science, accompanied by a growing emphasis on computer-related courses intended to prepare students for participation in the modern economy.

Tertiary-level school enrollments. Higher education, which once had the primary purpose of educating religious leaders, now acts as a gateway to better employment and often to a higher social status. Higher education is also where the greatest constriction of enrollments occurs. Worldwide, fewer than one-fifth of those age 18–24 were engaged in some form of tertiary education in 1997, with fewer than 5 percent of those in the least-developed countries enrolled. By contrast, in the most industrialized and developed countries, higher-education enrollments reached approximately half of the age-group. In some countries access to higher education has come to be considered an entitlement or, alternatively, a social requirement for entry into the most prestigious occupations or high political offices.

Varied forms of higher education

Recent international trends in higher education include rapid growth of private institutions, closer ties to the marketplace (such as corporate sponsorship of university research), and institutional differentiation (such as specialization in particular subject areas or occupations). Postsecondary-learning options range from distance education and short-term courses to extended residential stays and postgraduate work at world-class institutions. Some of these trends stem from advances in communications and international travel. Developed countries not only provide more students with a greater variety of study options but also invest more heavily in the research-and-development infrastructure of higher education. However, regional differences in the capacity of higher-education systems to contribute to scientific research and technological innovation may constitute an even greater gap than differences in material wealth between the richest and poorest countries.

Other developments in formal education. At the other end of the school continuum, access to early childhood care and preschool education became increasingly important in preparing children for success in school. Although preschool enrollments expanded worldwide from 44 million in 1975 to approximately 100 million by 2000, in many countries access was not always guaranteed to the poorest and most marginalized members of society. Some countries, however, have attempted to provide universal preprimary education to all children for purposes of both child development and the socialization of individuals toward a national identity. In Italy an emphasis on early schooling was the result of social movements of the early 1960s; according to American sociologist William Corsaro and Italian psychologist Francesca Emiliani, the massive migration to cities and the participation of women in labour protests brought demands that the state provide basic social services—including education and publicly funded child care.

Contemporaneous experiences elsewhere were quite different. Political revolution in China, for example, changed the very nature of education. Although traditional Chinese culture had attached great importance to education as a means of enhancing a person's worth and career, by the end of the 1950s the Chinese government could no longer provide jobs adequate to meeting the expectations of those who had acquired some formal schooling. Furthermore, the anti-intellectualism inherent in the mass campaign periods of the Great Leap Forward and, especially, the Cultural Revolution diminished the status and quality of education. The damage done to China's human capital was so great that it took decades to make up the loss.

A shift to rapid and pragmatic economic development occurred in the late 1970s when China's educational system increasingly trained individuals in technical skills so that they could fulfill the needs of the advanced, modern economy. The overall trend in Chinese education reflected a combination of fewer students and higher scholastic standards, resulting in a steeply hierarchical educational system. At the turn of the 21st century, slightly more than one-third of the total population had completed primary schooling, while roughly one-tenth of all Chinese had finished a secondary school education; fewer than 4 percent had earned an advanced degree. By the end of the 20th century, however, higher-education enrollments in China were growing rapidly. The government had permitted the opening of private educational institutions and had begun to decentralize the overall governance of education.

Advancements in China

Literacy as a measure of success. Between 1950 and 2000, the worldwide illiteracy rate dropped from approximately 44 percent to 20 percent of the population aged 15 and older. Yet the number of illiterate people, according to UNESCO data, increased from approximately 700 million in 1950 to 862 million in 2000 because of rapid population growth in less-developed countries with inadequate education coverage. In the early 21st century, South Asia and sub-Saharan Africa remained among the regions with the highest illiteracy rates—at 44 percent and 40 percent, respectively. India and China, each with populations exceeding 1 billion and illiteracy rates of approximately 43 percent and 15 percent, respectively, accounted for a majority of the world's illiterate adults. Even in developed countries, illiteracy rates of less than 2 percent continue to mask sizable populations of minorities who cannot understand written communications.

EDUCATION AND EQUALITY OF OPPORTUNITY

Countries increase the social and economic opportunities for their citizens by increasing access to a basic education that includes instruction in math, language skills, science, history, civics, and the arts. The right of individuals to an educational program that respects their personality, talents and abilities, and cultural heritage has been upheld in various international agreements, including the 1948 Universal Declaration of Human Rights and the 1959 Declaration of the Rights of the Child. Other international declarations further promote the rights of adults and special groups—including disabled individuals as well as ethnic minorities, indigenous and tribal peoples, refugees, and immigrants—to an appropriate education. UNESCO became a driving force toward the goal of universal education, especially through its sponsorship of the World Conference on Education for All (held in Thailand in 1990), which established 2000 as the target date for universal primary education. In UNESCO's follow-up World Education Forum (held in Senegal in 2000), that goal was postponed until 2015—a realistic reflection of the difficulties of both enrolling and retaining students through a complete primary education. The target date of 2015 also became one of eight United Nations Millennium Development Goals (MDG) drafted in 2000. Steps toward the achievement of universal education were to be tracked by indicators such as literacy rates and enrollment ratios.

Universal primary education

Access to education. Despite these international conferences, treaties, and goals, by the end of the 20th century more than 120 million primary-school-age children worldwide remained outside formal education systems. Depending on the country, and especially its level of economic

development and its political system, the number of children not attending school ranged from fewer than 5 percent to well over 30 percent of the relevant age-group. Moreover, it is important to point out that high aggregate enrollment rates for any one region or country do not reveal how many children successfully complete the legally required years of schooling. In developing countries, repetition of grade levels and dropout rates take their toll, with frequently less than half of a student cohort completing primary schooling. The initial experience of many children is often one of failure. The problem may be as general as the enrollment of children who have never been exposed to formal schooling and who simply do not understand what is occurring in the classroom. Most frequently, the problem is inappropriate curricula and foreign languages of instruction. For example, Western content and languages of instruction are frequently employed in countries whose citizens would prefer their education systems to reflect their own cultures and national goals.

Exams and other selection devices

For those who complete the initial stages of schooling, examinations commonly serve as a filtering device for determining who shall go on to postprimary education. As countries develop economically, compulsory schooling is extended, and selective examinations are consequently instituted for entry into upper secondary and higher education. Education systems eventually introduce selection devices for the most advanced and prestigious levels and types of education. Central questions concerning the role of education in reproducing social status or opening up opportunity to everyone revolve around who has access to what levels and types of education, what is learned, and how the postschool outcomes of education affect occupational attainment, income, social status, and even power. A predominant theme in discussions of education in the late 20th and early 21st centuries has been equality of educational opportunity (EEO).

Implications for socioeconomic status. In the West a commonly used measure of social class is an index of socioeconomic status (SES), which usually takes into account occupational status, income, and education levels of children's families. To determine whether education systems are truly meritocratic in their workings and outcomes, several hypotheses need to be tested, using the SES index. In *The Limits and Possibilities of Schooling* (1993), American sociologist Christopher Hurn proposed one method of evaluating education systems over time. Hurn identified the following set of relationships between variables: first, the correlation between adults' educational attainment (years of schooling and degrees completed) and socioeconomic status should grow stronger over time; second, the correlation between parents' SES and the educational attainment of their children should diminish over time; and, third, the correlation between the SES of parents and that of their offspring should also decrease over time.

Not all of Hurn's tests of meritocracy, when applied to actual outcomes, have proved true. In the first case, international experience supports the proposition that education has become the strongest determinant of individuals' occupational status and chances of success in adult life. For the two other variables, however, the evidence does not demonstrate a decrease over time in the relationship between family background and children's educational attainment. Rather, the correlation between family SES and school success or failure appears to have increased worldwide in recent decades. Moreover, long-term trends suggest that, as societies industrialize and modernize, social class becomes increasingly important, compared with the role of school-related factors, in determining educational outcomes and occupational attainment.

Social status

Social consequences of education in developing countries. Evidence is similarly mixed with regard to gender equality in access to high-quality education and opportunities to enter nontraditional fields of study. Although international agencies and national governments have been active since the late 1980s in promoting education rights for girls and women, complex changes were not adopted swiftly. Of the 120 million children excluded from education systems around the turn of the 21st century, for example, more than half were girls, and nearly three-fourths were living in South Asia and sub-Saharan Africa. At the same time, of the nearly 900 million illiterate adults in the world at the beginning of the 21st century, almost two-thirds were women. Again, the greatest number and percentage of illiterate female adults were located in the poorest regions. If geographic location and ethnicity are taken into account, as many as two-thirds to three-fourths of rural indigenous women in the least-developed countries lack the basic literacy skills to claim their citizenship rights. In some contexts there are strong cultural, economic, and political obstacles to women's access to education. Despite these negative patterns, there have been indications of gains made by women. In many countries a majority of secondary-education graduates and university entrants are women. In the 1970s and '80s, women also began entering technical and professional fields such as engineering and computer science in greater numbers, although these advances had plateaued by the turn of the 21st century. In developed and developing countries alike, however, higher educational attainment for women does not translate into thorough equality in occupational status and income. Education nonetheless leads to healthier, more productive populations, which is why many international organizations argue that the best long-term strategy in the fight against AIDS is universal primary education.

Education and economic policies

The role of state. Equality of educational and occupational opportunity and outcomes for women as well as for other underprivileged groups (working-class, rural, and minority children) is dependent on mutually reinforcing economic and education policies. Comparative studies suggest that government policies favouring overall poverty reduction and wage equity can contribute to overcoming past educational and economic disadvantages.

Even poor countries have achieved outstanding results on international standardized achievement tests in the areas of language, mathematics, and science while also providing near-universal secondary education. One such example is Cuba, where education and health were viewed as fundamental components of the Cuban Revolution. Alternatively, Finland exemplifies a wealthier country whose students on average have performed well on various measures of achievement and where differences between top- and bottom-scoring schools and between various categories of students have been minimal. Such successes tend to occur in countries that give priority to investments in education, health, and other social services, while other positive academic results can be seen from governments that are willing to experiment with alternative forms of education.

Social and family interaction. Research further indicates that parent participation in schools is an important factor in their children's academic success. Generally, parents from more affluent backgrounds have both the resources and the confidence to play a more active role in schools and to act as advocates for their children. Moreover, the formal content of instruction and even the pedagogies employed tend to reflect the values, language, and instructional and learning patterns of the middle classes as well as the more privileged and powerful social classes. Various measures initiated by schools to equalize opportunities for less-advantaged groups include establishing closer and more systematic involvement of teachers with parents (rather than only when problems arise), arranging for parent-teacher conferences at convenient locations and times, making information about the workings of the education system and individual schools available in the home language, bilingual instruction, and focusing on children's strengths and abilities.

Alternative forms of education. Developments in communications and instructional technologies in the 21st century provide previously unimaginable opportunities for people of all ages to tap the vast stores of world knowledge. Many of these technologies inevitably bring forth new forms of socialization. Contradicting the long-term historical movement away from apprenticeships (or learning within the family setting) and toward institutionalized education controlled by central governments, distance learning has opened the possibilities of learning in multiple ways at various sites—all under the control of individual learners. Technologies that promise to bring people to-

gether to share knowledge and life experiences, conversely, may also lead to the isolation of individuals and to the absence of face-to-face interactions among peers and teachers that are critical to preparation for adult roles in society. Homeschooling has also raised concerns about childhood socialization, though consortia of homeschooling parents (whereby students can meet and attend classes with other home-based students) are increasingly common. The use of learning packages and degree programs exported from North America, Europe, and the Pacific (notably Australia) to the countries of the Southern Hemisphere, while providing opportunity for advanced studies, may also include culturally inappropriate content, disregard for traditional knowledge, and the displacement of local languages by an international language such as English.

Finally, it should be noted that, in addition to state-regulated schooling, there are many systems of education designated as "nonformal" and "popular." Many private and public agencies provide various forms of instruction, aimed at specific populations, to serve needs not met by public schooling. An internationally recognized example is BRAC (the Bangladesh Rural Action Committee), an NGO that combines community-based literacy and basic education programs with income-generating activities for girls and women. BRAC and other NGOs helped raise enrollments in Bangladeshi schools from 55 percent in 1985 to 85 percent by the 21st century.

In programs such as these, education for job entry, upgrading, or promotion occurs on a vast and systematic scale, sometimes offering educational certificates equivalent to college degrees for educational goals achieved while working. Religious institutions, as they have done in the past, instruct the young and old alike not only in sacred knowledge but in the values and skills required for participation in local, national, and transnational societies as well. And mass media may also be considered a parallel education system that offers worldviews and explanations of how society works, commonly in the form of entertainment, and that systematically reaches larger audiences than formal schooling. These parallel systems may complement, compete with, or even conflict with existing state-sponsored systems of schooling, and they provide challenges that current school systems, as in the past, must confront and reconcile as well as they can. (R.F.A.)

Parallel systems of education

Education for cultural continuity and change

THE RELATIONSHIP OF CULTURE AND EDUCATION

An understanding of the educational process cannot be achieved without studying the broader human process of cultural adaptation. Culture has been defined in a number of ways. In everyday use the word often refers to the beliefs, values, and meanings that bind a group of people together. In other times and places, the word *culture* has referred to a group's entire "way of life," including patterns of behaviour and uses of material artifacts. Indeed, humans are perhaps unique in the way that they invent and use material objects not only to meet their physical needs but also to create meaning. Among the social sciences, different concepts are used to describe the way culture is created and re-created in the educational process. In this discussion *culture* will refer to the symbolic meanings, communicated largely via material objects, through which the members of a society understand themselves, each other, and the world around them. Education is, in this context, the transmission and acquisition of this symbolic knowledge for understanding, controlling, and transforming the world.

Working in small societies, anthropologists conducted studies of informal teaching and learning, including the simple mechanisms of imitation or rote memorization, and emphasized the educative role of ritual for binding members of a society to a common cultural vision. Sociologists, on the other hand, have tended to examine institutions emerging from the industrialized, urbanized, and highly stratified societies of the 19th century. The rise of industrial capitalism and the consolidation of the nation-state as the most widely accepted political framework went hand in hand with the development of modern school systems.

Of course, education is much broader than schooling, which is an institution of more recent historical invention. Until the development of agriculture and the rise of city-states some 10,000 years ago, tribal societies likely educated their young through complex and deliberate practices but not in separate institutions like those now known as schools. Rather, education was probably a seamless part of everyday life and took place through the productive and ritual activities characterizing a society. A school, by comparison, is typically an age-graded, hierarchical setting where, as American anthropologist Judith Friedman Hansen described in *Sociocultural Perspectives on Human Learning* (1979), "learners learn vicariously, in roles and in environments defined as distinct from those in which the learning will eventually be applied." Mass school systems can be seen as products of industrialization, a phenomenon that originated in the 18th century and is characterized by the rise of capitalism, large-scale urbanization, the consolidation of the nation-state, and the ubiquity of the printing press. Since that time, much of human learning has been confined to schools. Especially after World War II, schools became the dominant format for learning in most areas of the world. Still, schools are no less influenced by culture than are other, informal means of education.

From an anthropological perspective, the educational process fundamentally oscillates between an emphasis on continuity and an emphasis on change. This is because progress of any kind requires a social group to adapt to novel circumstances through innovation and then to consolidate and perpetuate this adaptation through repeated instruction and inculcation. By utilizing culture in ways that other species use instinct, human groups have wrested a living from the environment and assured themselves of biological and social continuity.

After many years of focusing on processes of cultural transmission as a central means of achieving cultural continuity, anthropologists and sociologists in the mid-20th century began to examine more closely how education contributed not to continuity but to change. If cultural transmission occurred smoothly, how did societies challenge their own inertia? If education served mainly to mold the young into the cultural patterns of a society, how did innovation ever occur? With such questions scholars moved away from studies of cultural transmission and the role of teachers and turned their attention to cultural acquisition and the role of the learner. How did relatively novice individuals acquire the basic cultural knowledge of a society, and what distinctive interests and traits might they bring to the learning process? This question spawned a tremendously fruitful collaboration between anthropology and psychology, giving rise to the new field of cross-cultural psychology. The work of Soviet psychologist Lev Semyonovich Vygotsky and the "sociohistorical school" that he helped found in the early part of the 20th century became central to this field. In books such as *Thought and Language* (1934), Vygotsky placed emphasis on the role of symbolic "tools of mediation" in the relation between individual and society. Cross-cultural psychology has been especially adept at showing how both peer group socialization and good teaching utilize tools of mediation in moving students to higher and more complex forms of cognition. More recently, American cognitive anthropologist Jean Lave and Swiss cognitive theorist Etienne Wenger proposed a theory of "situated learning," in which society is fundamentally composed of overlapping "communities of practice" that serve as the vehicles for cultural acquisition. Their account places identity at the hub of cultural learning. According to Lave and Wenger in *Situated Learning* (1991), as one moves from "legitimate peripheral participation" to a more central, expert role in a community of practice, one increasingly develops identities of mastery and their corresponding emotional investments. Becoming either a skilled midwife or a champion race-car driver, for instance, involves powerful learning processes that firmly situate the learner within a particular community.

Inquiry into the basis of innovation

An important overarching concept in the processes of cultural transmission and acquisition is that of cultural production. Even if education is oriented primarily to

achieving continuity, in a relatively closed system, the theoretical possibility of modification and change always exists. In the process of acquiring cultural knowledge, individuals or subcultures can modify or extend the knowledge, in effect organizing it for themselves while producing and adding new knowledge to the common stock. For example, while a carpenter is in the process of teaching an apprentice the techniques of stair laying as well as the cultural value of precision, the apprentice may discover a new cut that saves time without sacrificing much precision. The communication of this new technique becomes an act of cultural production. Over time, the change may be adopted by most carpenters, or some may deem it too sloppy a compromise. As Hansen observed, "The transmission of knowledge is subject both to conservative forces and to tendencies toward continual redefinition."

Cultural production

A final set of terms helps to further conceptualize the role education plays in cultural continuity and change. *Enculturation* refers to the process of cultural transmission by which individuals acquire the basic meanings and understandings of their primary culture, usually the local community or kin group. This primary enculturation can be supplemented or replaced by incorporation into nonlocal and, in many cases, foreign cultural systems. Subsequent cultural influences are described by the term *acculturation*, which refers to the kind of learning that occurs when a person from one culture comes in contact with another, usually dominant, culture. A more extreme form of acculturation is described by the term *assimilation*—something akin to a supplanting of one set of cultural values with another. Assimilation typically occurs most strongly under situations of either classic colonialism or internal colonialism, as in the case of Native Americans sent to boarding schools in the late 1800s and early 1900s to be shaped "in the white man's image." Yet in a deeper sense, most children undergo some form of acculturation every year, when they make the transition from the familiar environment of their homes and communities to the relatively alien context of the school. Finally, with increasing contact between different societies and cultures as well as increasing recognition of the value of cultural diversity, individuals may incorporate elements of various belief systems into a kind of hybrid personal belief system. This phenomenon, known as *transculturation*, has received increased attention, especially as globalization accelerates new flows of people and ideas and as transnational migration makes new kinds of identities possible.

HISTORICAL TENSIONS BETWEEN TRADITION AND INNOVATION

For hundreds of years, members of the modernizing West tended to view tribal societies as little more than exemplars of the remote past. Moderns erroneously perceived tribal societies to be locked in a state of evolutionary stasis, held there by a fixed repertoire of adaptive practices that had served them well for eons but that now ensured their doom under the crushing wave of modernization. Tribal education systems, it was thought, emphasized continuity above all. Conversely, industrial societies, which were understood as being dynamic, needed education systems that were oriented to change, adaptation, and innovation.

Closer examination has revealed the fallacy of such views. Tribal societies have continued to adapt to changing physical and social environments, and they have proved remarkably resilient. Their educational practices, while typically embedded in everyday activities, nevertheless can show an openness to observation and insight that is characteristic of the best empirical science. They engage in cultural production as much as they do cultural transmission. Moreover, so-called industrial societies, while employing the more efficient and abstracted technique of mass schooling, can settle into their own stagnation. In *Culture Against Man* (1963), American anthropologist Jules Henry discovered, somewhat to his surprise, that much contemporary learning in school was rote and that the fear of change was strong. More often than not, some have therefore implied, modern schools have educated for a kind of stultifying obedience, and there is ample evidence that contemporary schools of the nation-state may not necessarily succeed in preparing children adequately for a changing world. Thus, elements of continuity and change in varying degrees form a part of any educational endeavour. All societies undergo historical processes of continuity and change, and all societies engage in a kind of ongoing cultural debate about the proper uses of education. This is as true of nation-states as it is of more circumscribed cultural groups, such as first-generation Cambodians in the United States or the indigenous Ainu of Japan.

Dynamic relationship of continuity and change

Indeed, in the Western experience perhaps nothing better illustrates the tension between continuity and change than the debates between churchmen and Enlightenment thinkers of 17th- and 18th-century Europe. Although there were notable exceptions prior to this time, the Catholic legacy in Europe held that knowledge could be only divinely revealed and human affairs divinely regulated. In general, both formal and nonformal means of education tended to perpetuate a conservative view that was oriented toward continuity. Yet French author Voltaire, Scottish philosopher David Hume, and other Enlightenment thinkers sought to place the pursuit of knowledge squarely in the human realm. Arguing that only through a rational, empirical apprehension of the world could social progress occur, Enlightenment philosophers sought to provide the conceptual foundations for a dynamic humanistic science. Nevertheless, even today, religious education exists side by side with public-school systems that may instill a strong sense of skepticism and the scientific method. Such seemingly contradictory orientations can coexist because in their everyday lives people strive to make sense of their world.

The Mesoamerican world of present-day Mexico and Central America provides still other rich examples of the tension between continuity and change. Both the Mayan and the Aztec civilizations, at their height of development about AD 900 and 1500, respectively, developed elaborate educational practices to facilitate cultural adaptation and sustain cohesive worldviews. Both were deeply religious societies that sought to use strong educational means to situate everyday activities within a cosmic order. The Aztecs developed one of the first compulsory schools, called the *cuicacalli* ("house of song"), in which all children age 12 to 15 would learn sacred songs and gain knowledge of the ritual cycle. Meanwhile, specialized schools existed for the training of both warriors and priests. Aztec education emphasized the memorization and transmission of vital aspects of group knowledge. Less is known about the earlier Mayan civilization, but it is possible to infer a strong emphasis on social conformity. While the Mayan and Aztec education systems would seem overwhelmingly oriented toward continuity and preservation, each in its own way also facilitated experimentation and change. The Maya, for instance, would never have been able to develop their impressive knowledge of astronomy and mathematics had their educational processes—however inspired by oppressive and fanatical rulers—not fostered a spirit of empirical inquiry.

Centuries later, the early leaders of the United States of America faced an educational dilemma that also threw the perennial balance between continuity and change into relief. Basic education was conveyed by a family or learned through community responsibility during the American colonial period, and most children learned only the rudiments of reading, writing, and arithmetic along with Bible study and religious instruction. Only a very select few, especially from the larger towns, continued on to more formal education for the professions or the ministry, while other forms of vocational training were arranged through apprenticeships. Education was thus generally an affair of continuity. After the American Revolution of the late 1700s, statesmen such as Thomas Jefferson and Benjamin Rush advocated the development of a national education system that would develop basic skills and, most important, consolidate the gains of a growing democracy. In Rush's mind local allegiances and prejudices might compromise the integrity of the republic, so he argued for a strong brand of patriotic learning. Jefferson, meanwhile, emphasized literacy and history, hoping that schools might equip citizens of the new democracy with the tools to safeguard liberty against would-be tyrants. Partly because of

Education and democracy

popular reticence to embrace such lofty goals, neither Rush's nor Jefferson's visions were ever fully realized. It would take another 50 years, and the growth of a common school movement under the leadership of politician and educator Horace Mann, to lay the foundation for mass schooling in the United States. Even then, Mann succeeded in large part by striking a balance between continuity and change. As secretary of the Massachusetts Board of Education (1837–48), Mann urged wealthier citizens to support common schools for the sake of teaching productive industrial skills and keeping the social peace through the inculcation of Christian moral virtues. Meanwhile, he promoted the common school to the poor and disenfranchised as a way to build self-sufficiency and produce personal wealth. Common schools were thus meant to empower the poor and provide them with the tools to change their lives, yet they were also conceived as places to create social harmony and thereby validate the status quo.

MODERN EXAMPLES OF CONTINUITY AND CHANGE

Political patterns. An early 20th-century example of education's multifaceted role can be found in Mexico. On the heels of the Mexican Revolution, in 1921 the new government set about designing Mexico's first system of mass education. Preserving many of the principles of the country's liberal constitution and worldview (some of which represented a backlash against the Catholic church and its schools, postrevolutionary education in Mexico attempted to strike a balance between creating a dynamic scientific culture to drive national development and creating national unity to preserve the social gains of the revolution. Educational goals and emphases would vary throughout the succession of postrevolutionary governments. As the first head of Mexico's new national Ministry of Public Education, José Vasconcelos sought in the 1920s to build a new "cosmic race" of Mexicans through a critical, literary education. "Cultural missions" also brought the latest knowledge to remote rural communities. Then there was a shift to the "socialist education" of President Lázaro Cárdenas (1934–40), which highlighted class struggle and the need for a scientifically literate working class. After 1940 the pendulum swung back to a more conservative emphasis on national unity, a strong work ethic, and technical expertise.

Similar examples can be identified in Russia after its 1917 revolution or in China after its 1949 revolution. In these two cases, through a series of educational reforms, a communist regime struggled to transform a rural country into an industrial powerhouse and to impose ideological unity. In both Russia and China, as well as in Mexico, revolutionary regimes managed to create powerful national cultures in which most citizens participated. Only much later, under shifting political and ideological conditions, did those revolutionary powers begin to lose their hold.

National identity

Ideological patterns. A more contemporary example of differing orientations is the debate between those who believe education should provide the means for mastering a common body of knowledge and a common culture and those who advocate education for "liberation" and personal growth. American literary critic and educator E.D. Hirsch, Jr.'s notion of "cultural literacy" placed the highest value on building a common stock of historical and civic knowledge, even through means of rote memorization. Emphasizing outcomes more than means, Hirsch believed schools create the greatest opportunity for students of all backgrounds when they provide a common enculturation that is ultimately shared by all citizens of a nation.

On the other hand, Brazilian educator Paulo Freire, whose work became influential in many parts of the world, emphasized the means and process of education. He developed an educational method he believed would liberate socially oppressed peoples from the worldviews imposed upon them by social and political leaders. In Freire's terms education must be for "critical consciousness"—that is, for the ability to see oneself as an active agent who can transform the world and thereby create new knowledge. Freire rejected Hirsch's "cultural literacy" as one more guise of elite cultural imposition, through the means of what Freire sardonically called a "banking" approach to education. Likewise, Hirsch criticized what he viewed as ideological polarizations such as Freire's for being too facile, noting that even Antonio Gramsci, a founder of the Italian Communist Party, had recognized that "political progressivism demanded educational traditionalism."

The enduring contest between continuity and change. Around the world, current educational problems testify to the ever-present tension between education for cultural continuity and education for change. In nearly every country of the world, school attendance inspires children to question and challenge traditional social roles. Members of herding families in Africa, for instance, may want their sons to gain the skills of basic schooling in order to better defend their interests or bargain with traders, but they still expect the boys to assume the ritual responsibilities of adulthood and master the herding enterprise. Yet when the boys learn about the wider world, they often aspire to professional careers in the larger cities. Their opportunities may be perceived as coming at the cost of solidarity with the kinship group or village. Likewise, girls may draw on images of "modern" careers and press for permission to pursue advanced schooling instead of marrying young, bearing children, and keeping house. In places such as contemporary Iran, in the words of Iranian educator Golnar Mehran, young women—though obliged to veil themselves and accept single-sex education—can still take advantage of the "paradox of tradition and modernity" in pursuing previously unavailable careers. Meanwhile, even in the United States, cultural and religious minorities such as the Amish continue to eschew public schooling because of its perceived threat to their cultural continuity and integrity.

Paradox of tradition and modernity

Too often, the paths of postprimary education and commitment to one's local community are conceived as mutually exclusive options; by choosing one, students seem to be closing off the other. Yet there is also evidence that young men and women are learning to negotiate these conflicting choices, creating new, hybrid identities through a kind of pragmatic societal adaptation. In Mexican towns, while women might still be expected to marry at a young age, they are also increasingly encouraged to pursue a professional degree. The professional degree may come to signify not complete independence, as it does elsewhere, but rather the ability of women to "defend themselves" economically should their future husbands abandon them or fall on hard times. A similar phenomenon has occurred in Asian countries such as Japan and South Korea, where women now attend universities in numbers comparable to men but still may be limited to traditional female careers, with the anticipation that they will leave the job market to become wives and mothers.

Meanwhile, for young members of tribal communities, advanced schooling is no longer seen simply as the means to leave their indigenous identities behind. After a long history of assimilation through schooling, indigenous peoples can now selectively acculturate themselves to a dominant national culture while preserving existing cultural identities and commitments. Schools developed for the !Kung, Jul'hoansi (Julhoa), and other peoples of Botswana's Kalahari Desert have accomplished this. Because of encroachment by other groups upon their traditional hunting-and-gathering territory in the borderlands between Botswana and Namibia, the Jul'hoansi are now required to develop other economic skills. Yet the schools that enable this development have also given them various means of defending their traditional cultures. Such schools, set up in desert locations far from Botswana's cities, not only help integrate the tribal peoples into the modern Botswanan nation but also provide them with the critical skills to articulate their claims to indigenous rights and to advocate for themselves vis-à-vis an encroaching political world. Thus, the knowledge and credentials gained through schooling may indeed draw youth away from their cultures of origin and encourage their identification with other spheres of value, yet education may also provide students with tools for defending their indigenous lifestyle against contemporary culture.

Defending indigenous culture

Furthermore, schooling can foster unanticipated critical perspectives. While policy makers of a modern nation may

design a school system to effectively sort youth for a differentiated labour force, promote economic growth, and contribute to national unity, schools are never seamlessly effective in socializing students to a dominant worldview. Along the way, students are likely to acquire concepts, expectations, and skills that enable them to question the prevailing order. The youths in Papua New Guinea offer an illustration of what often happens when the expectation of social mobility fostered by schools meets the absence of viable employment. According to American anthropologist Peter Demerath, such contradictory conditions can lead to widespread disaffection and protest or, in the case of Papua New Guinea, a revival of traditional values and economic activities that challenge the state's modernist agenda. For example, from his studies in the village of Peri, Demerath noted that in the mid-1990s community members began to reemphasize traditional collective work parties, reciprocal exchange networks, and egalitarian rhetoric as a response to the individualism and social mobility fostered by the government. More dramatically, in many Arab countries populist policies and traditional views on the role of education once led governments to guarantee employment to college graduates. An era of high birth rates and poor economic performance in the late 20th century led to high rates of unemployment in countries such as Egypt and Saudi Arabia. Poor job prospects among those who had developed a sense of entitlement because of their academic performance contributed greatly to widespread disaffection. Many such alienated youths—mostly young, single men—adopted extreme versions of nativism and rejected a system that they came to view as corrupt and bound to Western institutions and values. Thus, schools may be seen as institutions that uphold the values of a nation or contribute to a stable economic system, but they are also capable of planting the seeds of unrest or radical change.

External influences. Around the world a burgeoning media culture oriented toward the young has unsettled traditional authority relations between the generations. Children and youths may learn through the media that their elders are out of step with the latest values and trends. Electronic music may be listened to more often than traditional strings and drums; computer programs may displace oral tradition. Local means of enculturation can be seen as limiting, while other cultural influences experienced through the global media open up a vast new symbolic community that can flatten existing hierarchies. In effect, the young become the most active cultural producers of new meanings for education.

Flattening of traditional hierarchies

While popular culture can certainly provide a source of generational antagonism, school-based pedagogies and curricula may also drive a wedge between youths and their cultures of origin. Either intentionally or unintentionally, teachers often denigrate students' home languages and dialects as inferior, or they devalue the kinds of skills and values that students bring to school.

Because schools historically have been used to build national cultures and identities, the countries that constitute the European Union (EU) face interesting new challenges. For decades, if not centuries, schools in European countries had inculcated children with strong national identities. With the creation of the EU, these same schools were asked to create a pan-European identity. The rest of the world looked to see how Europe would educate its young for continuity (strong national identity) and change (new pan-European identity). For instance, if French national identity was at one time constructed through textbook accounts of a glorious historical past in which neighbours such as the Germans and the Italians were portrayed in negative or inferior terms, how could that portrait of the past be reconciled with a pan-European present?

Similarly, South American schools are beginning to reverse the historical dominance of Spanish speakers over speakers of indigenous languages. Formerly designed to assimilate indigenous peoples into a Hispanic culture, such schools now have the mission of providing bilingual education for a pluralist nation. Finally, the intense growth of worldwide transnational migration over the course of the 20th century and into the 21st has created ever-more-pointed dilemmas for the national orientation of most education systems. Migration has always created dramatic educational tensions. Wrenched suddenly from a familiar cultural world, refugees and immigrants must make their way in a foreign society. The new host society may ask immigrants to question, modify, or even discard existing identities and values. This often happens through a kind of strong assimilation, in which schools and other educational agencies teach young immigrants to acculturate themselves to the new milieu. It may continue to occur in succeeding generations, long after the initial migration and settlement. Yet changes in transportation, communication technologies, and multicultural education policies have provided the conditions for embracing multiple identities. No longer forced to choose one identity and reject another, transnational migrants may become "transculturated." In other words, they may develop a sense of comfort in between the differing influences—what some have called transnational or hybrid identities.

Hybrid identities

Does the development of these transcultural identities augur a new era of global change, or does it simply represent the latest means for some to create continuity between the past and the present? Spanish sociologist Manuel Castells, in *The Power of Identity* (1997), suggested that globalization would produce a qualitatively different and new learning context that placed greater emphasis on adaptability and change through usage of electronic media. American political scientist Samuel P. Huntington, however, in *The Clash of Civilizations and the Remaking of World Order* (1996), suggested that the challenges of globalization would further unify certain social groups while alienating them from others. Such groups may seek to emphasize education for continuity in the face of bewildering change. In proposing solutions to this tension, scholars have tried to develop education models that will reinforce a group's strong local identities while encouraging group members to recognize their involvement with the broader global community. (B.A.U.L.)

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History of Education

Education can be thought of as the transmission of the values and accumulated knowledge of a society. In this sense, it is equivalent to what social scientists term socialization or enculturation. Children—whether conceived among New Guinea tribespeople, the Renaissance Florentines, or the middle classes of Manhattan—are born without culture. Education is designed to guide them in learning a culture, molding their behaviour in the ways of adulthood, and directing them toward their eventual role in society. In the most primitive cultures, there is often little formal learning, little of what one would ordinarily call school or classes or teachers; instead, frequently, the entire environment and all activities are viewed as school and classes, and many or all adults act as teachers. As societies grow more complex, however, the quantity of knowledge to be passed on from one generation to the next becomes more than any one person can know; and hence there must evolve more selective and efficient means of cultural transmission. The outcome is formal education—the school and the specialist called the teacher.

As society becomes ever more complex and schools become ever more institutionalized, educational experience becomes less directly related to daily life, less a matter of showing and learning in the context of the workaday world, and more abstracted from practice, more a matter of distilling, telling, and learning things out of context. This concentration of learning in a formal atmosphere allows children to learn far more of their culture than they are able to do by merely observing and imitating. As society gradually attaches more and more importance to education, it also tries to formulate the overall objectives, content, organization, and strategies of education. Literature becomes laden with advice on the rearing of the younger generation. In short, there develop philosophies and theories of education.

This article deals with the evolution of the formal teaching of knowledge and skills in all parts of the world and with the various philosophies that have inspired the resulting diverse systems. A further discussion of educational theory can be found in the article PHILOSOPHIES OF THE BRANCHES OF KNOWLEDGE. The teaching profession and the functions and methods of teachers are treated in TEACHING.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 561 and 562, and the *Index*.

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Education in primitive and early civilized cultures

PREHISTORIC AND PRIMITIVE CULTURES

The term education can be applied to primitive cultures only in the sense of enculturation, which is the process of cultural transmission. A primitive person, whose culture is the totality of his universe, has a relatively fixed sense of cultural continuity and timelessness. The model of life is relatively static and absolute, and it is transmitted from one generation to another with little deviation. As for prehistoric education, it can only be inferred from educational practices in surviving primitive cultures.

The purpose of primitive education is thus to guide children to becoming good members of their tribe or band. There is a marked emphasis upon training for citizenship, because primitive people are highly concerned with the growth of individuals as tribal members and the thorough comprehension of their way of life during passage from prepuberty to postpuberty.

Because of the variety in the countless thousands of primitive cultures, it is difficult to describe any standard and uniform characteristics of prepuberty education. Nevertheless, certain things are practiced commonly within cultures. Children actually participate in the social processes of adult activities, and their participatory learning is based upon what the American anthropologist Margaret Mead has called empathy, identification, and imitation. Primitive children, before reaching puberty, learn by doing and observing basic technical practices. Their teachers are not strangers but, rather, their immediate community.

Particpatory learning in primitive societies

In contrast to the spontaneous and rather unregulated imitations in prepuberty education, postpuberty education in some cultures is strictly standardized and regulated. The teaching personnel may consist of fully initiated men, often unknown to the initiate though they are his relatives in other clans. The initiation may begin with the initiate being abruptly separated from his familial group and sent to a secluded camp where he joins other initiates. The purpose of this separation is to deflect the initiate's deep attachment away from his family and to establish his emotional and social anchorage in the wider web of his culture.

The initiation "curriculum" does not usually include practical subjects. Instead, it consists of a whole set of cultural values, tribal religion, myths, philosophy, history, rituals, and other knowledge. Primitive people in some cultures regard the body of knowledge constituting the initiation curriculum as most essential to their tribal membership. Within this essential curriculum, religious instruction takes the most prominent place.

EDUCATION IN THE EARLIEST CIVILIZATIONS

The Old World civilizations of Egypt, Mesopotamia, and North China. The history of civilization started in the Middle East about 3000 BC, whereas the North China civilization began about a millennium and a half later. The Mesopotamian and Egyptian civilizations flourished almost simultaneously during the first civilizational phase (3000–1500 BC). Although these civilizations differed, they shared monumental literary achievements. The need for the perpetuation of these highly developed civilizations made writing and formal education indispensable.

Egypt. Egyptian culture and education were preserved and controlled chiefly by the priests, a powerful intellectual elite in the Egyptian theocracy who also served as the political bulwarks by preventing cultural diversity. The humanities as well as such practical subjects as science, medicine, mathematics, and geometry were in the hands of the priests, who taught in formal schools. Vocational skills relating to such fields as architecture, engineering, and sculpture were generally transmitted outside the context of formal schooling.

Priestly control of Egyptian and Babylonian education

Egyptians developed two types of formal schools for privileged youth under the supervision of governmental officials and priests: one for scribes and the other for priest trainees. At the age of five, pupils entered the writing school and continued their studies in reading and writing until the age of 16 or 17. At the age of 13 or 14, the schoolboys were also given practical training in offices for which they were being prepared. Priesthood training began at the temple college, which boys entered at the age of 17, the length of training depending upon the requirements for various priestly offices. It is not clear whether or not the practical sciences constituted a part of the systematically organized curriculum of the temple college.

Rigid method and severe discipline were applied to achieve uniformity in cultural transmission, since deviation from the traditional pattern of thought was strictly prohibited. Drill and memorization were the typical methods employed. But, as noted, Egyptians also used a work-study method in the final phase of the training for scribes.

Mesopotamia. As a civilization contemporary with Egyptian civilization, Mesopotamia developed education quite similar to that of its counterpart with respect to its purpose and training. Formal education was practical and aimed to train scribes and priests. It was extended from basic reading, writing, and religion to higher learning in law, medicine, and astrology. Generally, youth of the upper classes were prepared to become scribes, who ranged from copyists to librarians and teachers. The schools for priests were said to be as numerous as temples. This in-

dicates not only the thoroughness but also the supremacy of priestly education. Very little is known about higher education, but the advancement of the priestly work sheds light upon the extensive nature of intellectual pursuit.

As in the case of Egypt, the priests in Mesopotamia dominated the intellectual and educational domain as well as the applied. The centre of intellectual activity and training was the library, which was usually housed in a temple under the supervision of influential priests. Methods of teaching and learning were memorization, oral repetition, copying of models, and individual instruction. It is believed that the exact copying of scripts was the hardest and most strenuous and served as the test of excellence in learning. The period of education was long and rigorous, and discipline was harsh.

North China. In North China, the civilization of which began with the emergence of the Shang era, complex educational practices were in effect at a very early date. In fact, every important foundation of the formation of modern Chinese character was already established, to a great extent, more than 3,000 years ago.

Moral emphases of Chinese education

Chinese ancient formal education was distinguished by its markedly secular and moral character. Its paramount purpose was to develop a sense of moral sensitivity and duty toward people and the state. Even in the early civilizational stage, harmonious human relations, rituals, and music formed the curriculum.

Formal colleges and schools probably antedate the Chou dynasty of the 1st millennium BC, at least in the imperial capitals. Local states probably had less-organized institutions, such as halls of study, village schools, and district schools. With regard to actual methods of education, ancient Chinese learned from bamboo books and obtained moral training and practice in rituals by word of mouth and example. Rigid rote learning, which typified later Chinese education, seems to have been rather condemned. Education was regarded as the process of individual development from within.

The New World civilizations of the Maya, Aztec, and Inca. The outstanding cultural achievements of the pre-Columbian civilizations are often compared with those of Old World civilizations. The ancient Mayan calendar, which surpassed Europe's Julian calendar in accuracy, was, for example, a great accomplishment demonstrating the extraordinary degree of knowledge of astronomy and mathematics possessed by the Maya. Equally impressive are the sophistication of the Inca's calendar and their highway construction, the development of the Maya's complex writing system, and the magnificent temples of the Aztec. It is unfortunate that archaeological findings and written documents hardly shed sufficient light upon education among the Maya, Aztec, and Inca. But from available documents it is evident that these pre-Columbian civilizations developed formal education for training the nobility and priests. The major purposes of education were cultural conservation, vocational training, moral and character training, and control of cultural deviation.

The Maya. Being a highly religious culture, the Maya regarded the priesthood as one of the most influential factors in the development of their society. The priest enjoyed high prestige by virtue of his extensive knowledge, literate skills, and religious and moral leadership, and high priests served as major advisers of the rulers and the nobility. To obtain a priesthood, which was usually inherited from his father or another close relative, the trainee had to receive rigorous education in the school, where priests taught history, writing, methods of divining, medicine, and the calendar system.

Priestly control of Maya and Aztec education

Character training was one of the salient features of Mayan education. The inculcation of self-restraint, cooperative work, and moderation was highly emphasized in various stages of socialization as well as on various occasions of religious festivals. In order to develop self-discipline, the future priest endured a long period of continence and abstinence, and, to develop a sense of loyalty to community, he engaged in group labour.

The Aztec. Among the Aztec, cultural preservation relied heavily upon oral transmission and rote memorization of important events, calendrical information, and religious knowledge. Priests and noble elders, who were called conservators, were in charge of education. Since one of the important responsibilities of the conservator was to censor new poems and songs, he took the greatest care in teaching poetry, particularly divine songs.

At the *calmecac,* the school for native learning where apprenticeship started at the age of 10, the history of Mexico and the content of the historical codices were systematically taught. The *calmecac* played the most vital role in ensuring oral transmission of history through oratory, poetry, and music, which were employed to make accurate memorization of events easier and to galvanize remembrance. Visual aids, such as simple graphic representations, were used to guide recitation phases, to sustain interest, and to increase comprehension of facts and dates.

The Inca. The Inca did not possess a written or recorded language as far as is known. Like the Aztec, they also depended largely on oral transmission as a means of maintaining the preservation of their culture. Inca education was divided into two distinct categories: vocational education for common Inca and highly formalized training for the nobility. As the Inca empire was a theocratic, imperial government based upon agrarian collectivism, the rulers were concerned about the vocational training of men and women in collective agriculture. Personal freedom, life, and work were subservient to the community. At birth an individual's place in the society was strictly ordained, and at five years of age every child was taken over by the government, and his socialization and vocational training were supervised by government surrogates.

Education for the nobility consisted of a four-year program that was clearly defined in terms of the curricula and rituals. In the first year the pupils learned the Quechua language, the language of the nobility. The second year was devoted to the study of religion and the third year to learning about the quipus, a complex system of knotted coloured strings or cords used for sending messages and recording historical events. In the fourth year major attention was given to the study of history, with additional instruction in sciences, geometry, geography, and astronomy. The instructors were highly respected encyclopaedic scholars known as *amautas.* After the completion of this education, the pupils were required to pass a series of rigorous examinations in order to attain full status in the life of the Inca nobility. (N.S.)

Education in classical cultures

ANCIENT INDIA

The Hindu tradition. India is the site of one of the most ancient civilizations in the world. About the 2nd millennium BC the Aryans entered the land and came into conflict with the *dāsas,* or the non-Aryan tribes. They defeated them, spread far and wide in the country, established large-scale settlements, and founded powerful kingdoms. In the course of time, a section of the intellectuals, the Brahmans, became priests and men of learning; another group, nobles and soldiers, became Kṣatriyas; the agricultural and trading class was called Vaiśyas; and finally the *dāsas* were absorbed as Śūdras, or domestic servants. Such was the origin of the division of the Hindus into four varnas, or "classes." By about 500 BC, the classes became hardened into castes.

Religion was the mainspring of all activities in ancient India. It was of an all-absorbing interest and embraced not only prayer and worship but philosophy, morality, law, and government as well. Religion saturated educational ideals, too, and the study of Vedic literature was indispensable to higher castes. The stages of instruction were very well defined. During the first period, the child received elementary education at home. The beginning of secondary education and formal schooling was marked by a ritual known as the *upanayana,* or thread ceremony, which was restricted to boys only and was more or less compulsory for boys of the three higher castes. The Brahman boys had this ceremony at the age of eight, the Kṣatriya boys at the age of 11, and the Vaiśya boys at the age of 12 years. The boy would leave his father's house and enter his preceptor's *āśrama,* or home, situated amid sylvan surroundings.

The Vedic tradition in Hindu education

The *ācārya* would treat him as his own child, give him free education, and not charge anything for his boarding and lodging. The pupil had to tend the sacrificial fires, do the household work of his preceptor, and look after his cattle.

The study at this stage consisted of the recitation of the Vedic mantras, or "hymns," and the auxiliary sciences—phonetics, the rules for the performance of the sacrifices, grammar, astronomy, prosody, and etymology. The character of education, however, differed according to the needs of the caste. For a child of the priestly class, there was a definite syllabus of studies. The *trayī-vidyā,* or the knowledge of the three Vedas, the most ancient of Hindu scriptures, was obligatory for him. During the whole course at school, as at college, the student had to observe brahmacharya—that is, wearing a simple dress, living on plain food, using a hard bed, and leading a celibate life.

The period of studentship normally extended to 12 years. For those who wanted to continue their studies, there was no age limit. After finishing their education at an *āśrama,* or forest school, they would join a higher centre of learning or a university presided over by a *kulapati* (a founder of a school of thought). Advanced students would also improve their knowledge by taking part in philosophical discussions at a *parisad,* or "academy." Education was not denied to women, but normally girls were instructed at home.

The method of instruction differed according to the nature of the subject. The first duty of the student was to memorize the particular Veda of his school, with special emphasis placed on correct pronunciation. In the study of such literary subjects as law, logic, rituals, and prosody, comprehension played a very important role. A third method was the use of parables, which were employed in the personal spiritual teaching relating to the Upanishads, or conclusion of the Vedas. In higher learning, such as in the teaching of dharmashastra ("righteousness science"), the most popular and useful method was catechism—the pupil asking questions and the teacher discoursing at length on the topics referred to him. Memorization, however, played the greatest role.

The introduction of Buddhist influences. By about the end of the 6th century BC, the Vedic rituals and sacrifices had gradually developed into a highly elaborate cult that profited the priests but antagonized an increasing section of the people. Education became generally confined to the Brahmans, and the *upanayana* was being gradually discarded by the non-Brahmans. The formalism and exclusiveness of the Brahmanic system was largely responsible for the rise of two new religious orders, Buddhism and Jainism. Neither of them recognized the authority of the Vedas, and both challenged the exclusive claims of the Brahmans to priesthood. They taught through the common language of the people and gave education to all, irrespective of caste, creed, or sex. Buddhism also introduced the monastic system of education. Monasteries attached to Buddhist temples served the double purpose of imparting education and of training persons for priesthood. A monastery, however, educated only those who were its members. It did not admit day scholars and thus did not cater to the needs of the entire population.

Buddhism and Jainism in Indian education

Meanwhile, significant developments were taking place in the political field that had repercussions on education. The establishment of the imperialistic Nanda dynasty in about 413 BC and then of the even stronger Mauryas some 40 years later shook the very foundations of the Vedic structure of life, culture, and polity. The Brahmans in large numbers gave up their ancient occupation of teaching in their forest retreats and took to all sorts of occupations; the Kṣatriyas also abandoned their ancient calling as warriors; and the Śūdras in their turn rose from their servile occupations. These forces produced revolutionary changes in education. Schools were established in growing towns, and even day scholars were admitted. Studies were chosen freely and not according to caste. Taxila had already acquired an international reputation in the 6th century BC as a centre of advanced studies and now improved upon it. It did not possess any college or university in the modern sense of the term, but it was a great centre of learning with a number of famous teachers, each having a school of his own.

In the 3rd century BC Buddhism received a great impetus under India's most celebrated ruler, Aśoka. After his death, Buddhism evoked resistance, and a counterreformation in Hinduism began in the country. About the 1st century AD there was also a widespread lay movement among both Buddhists and Hindus. As a result of these events, Buddhist monasteries began to undertake secular as well as religious education, and there began a large growth of popular elementary education along with secondary and higher learning.

Classical India. The 500 years from the 4th century AD to the close of the 8th, under the Guptas and Harṣa and their successors, is a remarkable period in Indian history. It was the age of the universities of Nālandā and Valabhī and of the rise of Indian sciences, mathematics, and astronomy. The university at Nālandā housed a population of several thousand teachers and students, who were maintained out of the revenues from more than 100 villages. Because of its fame, Nālandā attracted students from abroad, but the admission test was so strict that only two or three out of 10 attained admission. More than 1,500 teachers discussed over 100 different dissertations every day. These covered the Vedas, logic, grammar, Buddhist and Hindu philosophy (Sankhya, Nyaya, etc.), astronomy, and medicine. Other great centres of Buddhist learning of the post-Gupta era were Vikramaśīla, Odantapurī, and Jagaddala. The achievements in science were no less significant. Āryabhaṭa in the late 5th century was the greatest mathematician of his age. He introduced the concepts of zero and decimals. Varāhamihira of the Gupta age was a profound scholar of all the sciences and arts, from botany to astronomy and from military science to civil engineering. There was also considerable development of the medical sciences. According to contemporaries, more than eight branches of medical science, including surgery and pediatrics, were practiced by the physicians.

The university at Nālandā

These were the main developments in education prior to the Muslim invasions, beginning in the 10th century. Nearly every village had its schoolmaster, who was supported from local contributions. The Hindu schools of learning, known as *pathasalas* in western India and *tols* in Bengal, were conducted by Brahman *ācāryas* at their residence. Each imparted instruction in an advanced branch of learning and had a student enrollment of not more than 30. Larger or smaller establishments, specially endowed by rajas and other donors for the promotion of learning, also grew in number. The usual centres of learning were either some king's capital, such as Kanauj, Dhār, Mithilā, or Ujjayinī, or a holy place, such as Vārānasi, Ayodhyā, Kānchī, or Nasik. In addition to Buddhist viharas (monasteries), there sprang up Hindu *maṭhas* (monks' residences) and temple colleges in different parts of the country. There were also *agrahāra* villages, which were given in charity to the colonies of learned Brahmans in order to enable them to discharge their scriptural duties, including teaching. Girls were usually educated at home, and vocational education was imparted through a system of apprenticeship.

Indian influences on Asia. An account of Indian education during the ancient period would be incomplete without a discussion of the influence of Indian culture on Sri Lanka and Central and Southeast Asia. It was achieved partly through cultural or trade relations and partly through political influence. Khotān in Central Asia had a famous Buddhist vihara as early as in the 1st century AD. A number of Indian scholars lived there, and many Chinese pilgrims, instead of going to India, stayed there. Indian pandits (scholars) were also invited to China and Tibet, and many Chinese and Tibetan monks studied in Buddhist viharas in India.

The process of Indianization was at its highest in Southeast Asia. Beginning in the 2nd century AD Hindu rulers reigned in Indochina and in the numerous islands of the East Indian archipelago, from Sumatra to New Guinea, for a period of 1,500 years. These regions were peopled by primitive races, who adopted the civilization of their masters. A greater India was thus established by a general fusion of cultures. Some of the inscriptions of these countries, written in flawless Sanskrit, show the influence

Indianization of Southeast Asia

of Indian culture. There are references to Indian philosophical ideas, legends, and myths and to Indian astronomical systems and measurements. Hinduism continued to wield its influence on these lands so long as the Hindus ruled in India. This influence ceased by the 15th century AD. (S.N.M.)

ANCIENT CHINA

Ancient Chinese education served the needs of a simple agricultural society with the family as the basic social organization. Paper and the writing brush had not been invented, and the "bamboo books" then recorded to be in existence were of limited use at best. Oral instruction and teaching by example were the chief methods of education.

The molding of character was a primary aim of education. Ethical teachings stressed the importance of human relations and the family as the foundation of society. Filial piety, especially emphasizing respect for the elderly, was considered to be the most important virtue. It was the responsibility of government to provide instruction so that the talented would be able to enter government service and thus perpetuate the moral and ethical foundation of society.

Education and public service

The Chou period. *Western Chou* (*1111–771 BC*). This was the feudal age, when the feudal states were ruled by lords who paid homage to the king of Chou and recognized him as the "Son of Heaven."

Schools were established for the sons of the nobility in the capital city of Chou and the capital cities of the feudal states. Schools for the common people were provided within the feudal states in villages and hamlets and were attended, according to written records, by men and women after their work in the fields. There were elementary and advanced schools for both the ruling classes and the common people. Separate studies for girls were concerned chiefly with homemaking and the feminine virtues that assured the stability of the family system.

The content of education for the nobility consisted of the "six arts"—rituals, music, archery, charioteering, writing, and mathematics. They constituted what may be called the "liberal education" of the period. Mere memory work was condemned. As Confucius said of the ancient spirit of education, "learning without thought is labour lost."

Eastern Chou (*770–255 BC*). This was a period of social change brought about by the disintegration of the feudal order, the breakdown of traditional loyalties, the rise of cities and urban civilization, and the growth of commerce.

The instability and the perplexing problems of the times challenged scholars to propose various remedies. The absence of central control facilitated independent and creative thinking. Thus appeared one of the most creative periods in China's intellectual history, when a Hundred Schools of thought vied with one another to expound their views and proposals for attaining a happy social and political order. Some urged a return to the teachings of the sages of old, while others sought better conditions by radical change. Among the major "schools" of this age were Taoism, Confucianism, Mohism, and legalism. No one school was in the ascendancy. Each major school had its followers and disciples, among whom there was a vigorous program of instruction and intellectual discussion. Most active in the establishment of private schools were Confucius and his disciples, but the Taoists, the Mohists, and the legalists also maintained teaching institutions.

The Hundred Schools of thought

Another form of educational activity was the practice of the contending feudal states of luring to their domain a large number of scholars, partly to serve as a source of ideas for enhancing the prosperity of the state and partly to gain an aura of intellectual respectability in a land where the respect for scholars had already become an established tradition. The age of political instability and social disintegration was thus an age of free and creative intellectual activity. Conscious of their importance and responsibility, the scholars developed a tradition of self-respect and fearless criticism. It was this tradition that Confucius had in mind when he said that the educated person was not a utensil to be used, and it was this spirit that the Confucian philosopher Mencius described when he said that the great man was a man of principles whom riches and position could not corrupt, whom poverty and lowliness could not swerve, whom power and force could not bend.

The teachings of the Hundred Schools and the records of the feudal states meant a marked increase in literature and, consequently, in the materials for instruction. The classical age of China, the period of the Eastern Chou, left an intellectual and educational legacy of inestimable value. Its scholars propounded theories of government and of social and individual life that were as influential in China and East Asia as the Greek philosophers of almost contemporary age were in the Western world.

The Ch'in–Han period. *Ch'in autocracy* (*221–206 BC*). Of the various schools of thought that arose in China's classical age, legalism was the first to be accorded official favour. The policies of the Ch'in dynasty were based on legalist principles stressing a strong state with a centralized administration. Many of its policies were so different from past practices that they incurred the criticism of scholars, especially those who upheld the examples of the ancient sages. To stop the criticism, the ruler, who called himself the first emperor, acting upon the advice of a legalist minister, decreed a clean break with the past and a banning of books on history and of classics glorifying past rulers. Numerous books were collected and burned, and hundreds of scholars were put to death.

Though condemned for the burning of books and the persecution of scholars, the Ch'in dynasty laid the foundation for a unified empire and made it possible for the next dynasty to consolidate its power and position at home and abroad. In education, the unification efforts included a reform and simplification of the written script and the adoption of a standardized script intelligible throughout the country. First steps were taken toward uniform textbooks for the primary schools. The invention of the writing brush made of hair, as well as the making of ink, led to the replacement of the clumsy stylus and bamboo slips with writing on silk.

Scholarship under the Han (*206 BC–AD 220*). The Han dynasty reversed many of the policies of its short-lived predecessor. The most important change was a shift from legalism to Confucianism. The banned books were now highly regarded, and the classics became the core of education. An assiduous effort was made to recover the prohibited books and to discover books and manuscripts that scholars had concealed in secret places. Much painstaking work was done in copying and editing, and the textual and interpretative studies of the Han scholars accorded a new importance to the study of the classics. The making of paper further stimulated this revival of learning. Critical examination of old texts resulted in the practice of higher criticism long before it developed in the West.

Shift to Confucianism

There were historians, philosophers, poets, artists, and other scholars of renown in the Han dynasty. Deserving special mention is Ssu-ma Ch'ien, author of a monumental history of China from the earliest times to the 1st century BC, whose high level of scholarship earned him the title "Chinese Father of History." An illustrious woman of letters, Pan Chao, was named poet laureate. A bibliographer collected and edited ancient texts and designated them as classics. The first dictionary of the Chinese language was written. Since the discovery and interpretation of ancient texts had largely been the work of Confucian scholars, Chinese scholarship from now on became increasingly identified with Confucianism. Most of the Han rulers gave official sanction to Confucianism as a basis of conducting government and state affairs. There was, however, no action to exclude other schools of thought.

There were a variety of schools on the national and local levels. Increasing activity in private education continued, and much of the study of the classics and enriched literature was done in private schools. Of considerable influence in the country and abroad was a national university with an enrollment that soared to 30,000. The classics now became the core of the curriculum, but music, rituals, and archery were still included. The tradition of all-round education in the six arts had not vanished.

Introduction of Buddhism. The Han dynasty was a period of territorial expansion and growth in trade and cultural relations. Buddhism was introduced at this time.

Buddhist and Indian influences in China

Early information about Buddhism was probably brought into China by traders, envoys, and monks. By the 1st century AD an emperor became personally interested and sent a mission to India to seek more knowledge and bring back Buddhist literature. Thereafter, Indian missionaries as well as Chinese scholars translated Buddhist scriptures and other writings into Chinese.

Indian missionaries not only preached a new faith but also brought in new cultural influences. Indian mathematics and astronomical ideas enriched Chinese knowledge in these fields. Chinese medicine also benefited. Architectural and art forms reflected Buddhist and Indian influence. Hindu chants became a part of Chinese music.

For a couple of centuries after its introduction, however, Buddhism showed no signs of popular appeal. Han scholarship was engrossed in the study of ancient classics and was dominated by Confucian scholars who had scant interest in Buddhist teachings that were unconcerned with the practical issues of moral and political life. Moreover, the Buddhist view of evil and the Buddhist espousal of celibacy and escape from earthly existence were alien to China's traditions. Taoist scholars, finding in Buddhism much that seemed not too remote from their own spiritual message, were more inclined to study the new philosophy. Some of them aided in the translation of Buddhist texts, but they were not in the centre of the Han stage.

The fall of the Han dynasty was followed by a few hundred years of division, strife, and foreign invasions. China was not united again until the end of the 6th century. It was during this period that Buddhism gained a foothold in China. The literary efforts of Chinese monks produced a Chinese Buddhist literature, and this marked the beginning of a process that transformed an alien importation into a Chinese religion and system of thought.

(T.H.C.)

ANCIENT HEBREWS

Like all preindustrial societies, ancient Israel first experienced a type of education that was essentially familial; that is to say, the mother taught the very young and the girls, while the father assumed the responsibility of providing moral, religious, and handcraft instruction for the growing sons. This characteristic remained in Jewish education, for the relation of teacher to pupil was always expressed in terms of parenthood and filiation. Education, furthermore, was rigid and exacting; the Hebrew word *musar* signifies at the same time education and corporal punishment.

The education of scribes

Once they were established in Palestine—at the crossroads of the great literate civilizations of the Middle East, in the beginning of the 1st millennium BC—the Jewish people learned to develop a different type of education—one that involved training a specialized, professional class of scribes in a then rather esoteric art called writing, borrowed from the Phoenicians. Writing was at first practical: the scribe wrote letters and drew up contracts, kept accounts, maintained records, and prepared orders. Because he could receive written orders, he eventually became entrusted with their execution; hence the importance of scribes in the royal administration, well-attested since the times of David and Solomon. The training given these scribes, moreover, included training of character and instilling the high ideal of wisdom, as would befit the servants of the king.

Writing found another avenue of application in Israel—in religion. And the scribe again was the agent of education. He was the man who copied the sacred Law faithfully and established the canonical text. He was the one who read the Law to himself and to the people, taught it, and translated it when Hebrew ceased to be the vernacular or "living language" (into Greek in Alexandria, into Aramaic in Palestine); he explained it, commented on it, and studied its application in particular cases. After the downfall of Israel in 722–721 BC and Judah in 586 BC and their subjection to foreign rule, Jewish education became characterized more and more by this religious orientation. The synagogue in which the community assembled became not merely a house of prayer but also a school, with a "house of the book" (*bet ha-sefer*) and a "house of instruction" (*bet ha-midrash*) corresponding roughly to elementary and secondary or advanced levels of education. Girls, however, continued to be taught at home.

The role of writing in this Oriental world should not be exaggerated, of course: oral instruction still held first place by far. Although a pupil might learn to read aloud, or rather to intone his text, his main effort was to learn by heart fragment after fragment of the sacred Law. Alongside this written Law, however, there developed interpretations or exegeses of it, which at first were merely oral but which progressively were reduced to writing—first in the form of memoranda or aide-mémoire inscribed on tablets or notebooks, then in actual books. The diffusion of this religious literature called for an expansion of programs of instruction, evolving into diverse stages: elementary, intermediate, and advanced, the latter in several centres in Palestine, later in Babylonia. This religiously based education was to become one of the most important factors enabling Judaism to survive the national catastrophes of AD 70 and 135, involving the capture and subsequent destruction of Jerusalem. In their dispersion, the Jews clung to Hebrew, their only language for worship, for the study of the Law, for tradition, and consequently for instruction. From this evolved the respect with which the teacher was and is surrounded in Jewish communities.

ANCIENT GREEKS

Origins. The history of the Hellenic language and therewith of the Hellenic people goes back to the Mycenaean civilization of about 1400–1100 BC, which itself was the heir of the pre-Hellenic civilization of Minoan Crete. The Mycenaean civilization consisted of little monarchies of an Oriental type, with an administration operated by a bureaucracy, and it seems to have operated an educational system designed for the training of scribes, similar to those of the ancient civilizations of the Middle East. But continuity did not exist between this education and that which was to develop after a period of obscurity known as the Greek Dark Age, dating approximately from the 11th to the 8th century BC. When the Greek world reappeared in history, it was an entirely different society, one headed by a military aristocracy as idealized in Homer's *Iliad* and *Odyssey*. During this period, sons of the nobility received their education at the court of the prince in the setting of a guild companionship of warriors: the young nobleman was educated through the counsel and example of an older man to whom he had been entrusted or had entrusted himself, a senior admired and loved. It was in this atmosphere of virile camaraderie that there developed the characteristic ideal of Greek love that was enduringly to mark Hellenic civilization and to deeply influence its conception of education itself—for example, in the relation of master to pupil. Yet these warriors of the Archaic period were not coarse barbarians; by this time the Homerids (reciters of Homer) and the rhapsodists (singers-reciters and sometimes creative poets) were taking the great epics of Homer and Hesiod throughout the far-flung Greek settlements of the Mediterranean, and a new, cultivated civilization was already emerging. Dance, poetry, and instrumental music were well developed and provided an essential element in the educational formation of the dominant elites. In addition, the idea of *aretē* was becoming central to Greek life. The epics of Hesiod and Homer glorified physical and military prowess and promoted the ideal of the cultivated patriot-warrior who displayed this cardinal virtue of *aretē*, a concept difficult to translate but embodying the virtues of military skill, moral excellence, and educational cultivation. It was an ethic of honour, which made virtues of pride and of jealousy as the inspiration of great deeds and which accepted it as natural that one would be the object of jealousy or of enmity. Reverence for Homer, which until the end of antiquity (and in Byzantium even later) was to constitute the basis of Greek culture and therewith of Greek education, would maintain from generation to generation this "agonistic" ideal: the cult of the hero, of the champion, of high performance, which found an outlet outside the sphere of battles in games or contests (*agônes*), particularly in the realm of athletics, the most celebrated being the Olympic Games, dating traditionally from 776 BC.

Education in the Greek Archaic period

Profound changes were introduced into Greek education as a result of the political transformations involved in the maturing of the city-state. There developed a collective ideal of devotion to the community: the city-state (*polis*) was everything to its citizens; the city made its citizens what they were—mankind. This subordination of the individual exploit to collective discipline was reinforced by the strategic military revolution that saw the triumph of heavy infantry, the hoplites, foot soldiers heavily armed and in tight formation.

Sparta. It is in Sparta, the most flourishing city of the 8th and 7th centuries BC, that one sees to best advantage the richness and complexity of this archaic culture. Education was carried to a high level of artistic refinement, as evidenced by the events organized within the framework of the city's religious festivals. The young men and women engaged in processions, dances, and competitions in instrumental music and song. Physical education had a like part, equally for both sexes, given status by national or international contests (the Spartans regularly took more than half of the first places at the Olympic Games); but military and civic education dominated, as it was expected that the citizen-soldier be ready to fight and, if necessary, to die, for his country.

Spartan education for a warrior caste

This last aspect became not merely dominant but exclusive from the time (about 550 BC) when a conservative reaction triumphed at Sparta, bringing to power a militarist and aristocratic regime. Arts and sports gave way completely to an education appropriate to men of a warrior caste. The education of girls was subordinated to their future function as mothers; a strict eugenic regime pitilessly eliminated sickly and deformed children. Up to the age of seven, children were brought up by the women, already in an atmosphere of severity and harshness. Education, properly speaking, *agōgē*, lasted from age seven to 20 and was entirely in the hands of the state.

The male youth of Sparta were enrolled into formations corresponding to successive age classes, divided into smaller units under the authority of comrades of their own age or of young officers. It was a collective education, which progressively removed them from the family and subjected them to garrison life. Everything was organized with a view to preparation for military service: lightly clothed, bedded on the bare ground, the child was poorly fed, told to steal to supplement his rations, and subjected to rigorous discipline. His virility and combativeness were developed by hardening him to blows—thus the role of ritual brawls between groups of boys and of the institution of the *krypteia,* a nocturnal expedition designed both to terrify the lower classes of slaves (helots) and to train the future fighter in ambushes and the ruses of warfare. He was also, of course, directly apprenticed to the military craft, using arms and maneuvering in close formation. This puritanical education, proceeding in a climate of austerity, had as its sole norm the interests of the state, erected into a supreme category; the Spartan was trained under a strict discipline to obey blindly the orders of his superiors. Curiously, the child was at the same time trained to dissimulation, to lying, to theft—all virtues when directed toward the foreigner, toward whom distrust and Machiavellianism were encouraged.

This implacably logical education enabled Sparta to remain for long the most powerful city, militarily and diplomatically, of the entire Greek world and to triumph over its rival Athens after the long struggle of the Peloponnesian War (431–404 BC); but it did not prevent Sparta's decadence. Not that Sparta ever relaxed its tension: on the contrary, in the course of centuries, the rigour and ferocity were accentuated even as such behaviour became more and more anachronistic and without real use. Rites of initiation were transformed into barbarous tests of endurance, the boys undergoing flagellation and competing in enduring it, sometimes to the very death, under the eyes of tourists attracted by the sadistic spectacle. This occurred in times of complete peace when, under the Roman Empire, Sparta was nothing but a little provincial city with neither independence nor army.

Athens. Beginning at a date difficult to fix precisely (at the end of the 7th or during the 6th century), Athens, in contrast to Sparta, became the first to renounce education oriented toward the future duties of the soldier. The Athenian citizen, of course, was always obliged, when necessary and capable, to fight for the fatherland, but the civil aspect of life and culture was predominant: armed combat was only a sport. The evolution of Athenian education reflected that of the city itself, which was moving toward increasing democratization—though it should be noted that the slave and the resident alien always remained excluded from the body politic. The Athenian democracy, even in its most complete form, attained in the 4th century BC, was to remain always the way of life of a minority—about one-tenth, it is estimated, of the total population. Athenian culture continued to be oriented toward the noble life, that of the Homeric knight, minus the warrior aspect, and this orientation determined the practice of elegant sports. Some of these, such as horsemanship and hunting, always remained more or less the privilege of an aristocratic and wealthy elite; the various branches of athletics, however, originally reserved for the sons of the great families, became more and more widely practiced.

Athenian education for a democratic minority

Education of youth. Schools had begun to appear in those early centuries, probably on eastern Mediterranean models, run by private teachers. The earliest references are, however, more recent. Herodotus mentions schools dating from 496 BC and Pausanias from 491 BC. The term used is *didaskaleion* ("a place for instruction"), while the generic term *scholē,* meaning leisure—a reference to schooling being the preserve of the wealthier sector—was also coming into use. There was no single institution; rather, each activity was carried out in a separate place. The young boy of privileged rank would be taken by a kind of chaperon, the *paidagōgos,* who was generally a respected slave within the parents' household. The elements of literacy were taught by the writing master, known as a *grammatistes,* the child learning his letters and numbers by scratching them on a wax-coated wooden tablet with a stylus. More advanced formal literacy, chiefly in a study of the poets, playwrights, and historians, was given by the *grammatikos,* although this was restricted to the genuinely leisured. Supremely important was instruction in the mythopoeic legends of Hesiod and Homer, given by the lyre-playing *kitharistes.* In addition, all boys had to be instructed in physical and military activities in the wrestling school, known as the palaestra, itself part of the more comprehensive institution of the gymnasium.

The moral aspect of education was not neglected. The Athenian ideal was that of the *kalos k'agathos,* the "wise and good" man. The teachers were as much preoccupied with overseeing the child's good conduct and the formation of his character as with directing his progress in the various subjects taught him. Poetry served to transmit all the traditional wisdom, which combined two currents: the ethic of the citizen expressed in the moralizing elegies of the 6th-century lawmaker Solon and the old Homeric ideal of the value of competition and heroic exploit. But this ideal equilibrium between the education of the body and that of the mind was interrupted before long as a result on the one hand of the development of professional sports and the exigencies of its specialization and on the other by the development of the strictly intellectual disciplines, which had made great progress since the time of the first philosophers of the 5th century BC.

Sophistic education

Higher education. A system of higher education open to all—to all, at any rate, who had the leisure and necessary money—emerged with the appearance of the Sophists, mostly foreign teachers who were contemporaries and adversaries of Socrates (*c.* 470–399 BC). Until then, the higher forms of culture had retained an esoteric character, being transmitted by the master to a few chosen disciples, as in the first schools of medicine at Cnidus and at Cos, or within the framework of a religious confraternity involving initiate status. The Sophists proposed to meet a new need that was generally felt in Greek society, particularly in the most active cities such as Athens, where political life had been intensively developed. Henceforth, participation in public affairs became the supreme occupation engaging the ambition of Greek man; it was no longer in athletics and elegant leisure activities that his valour, his desire to

assert himself and to triumph, would find expression but rather in political action.

The Sophists, who were professional educators, introduced a form of higher education whose commercial success attested to and was promoted by its social utility and practical efficacy. They inaugurated the literary genre of the public lecture, which was to experience a long popularity. It was a teaching process that was oriented in an entirely realistic direction, education for political participation. The Sophists pretended neither to transmit nor to seek for the truth concerning man or existence; they offered simply an art of success in political life, which meant, above all, being able on every occasion to make one's point of view prevail. Two principal disciplines constituted the program: the art of logical argument, or dialectic, and the art of persuasive speaking, or rhetoric—the two most flourishing humanistic sciences of antiquity. These disciplines the Sophists founded by distilling from experience their general principles and logical structures, thus making possible their transmission on a theoretical basis from master to pupil.

To the pedagogy of the Sophists there was opposed the activity of Socrates, who, as inheritor of the earlier aristocratic tradition, was alarmed by this radical utilitarianism. He doubted that virtue could be taught, especially for money, a degrading substance. An heir also of the old sages of former times, Socrates held that the supreme ideal of man and hence of education was not the spirit of efficiency and power but the distinterested search for the absolute, for virtue—in short, for knowledge and understanding.

It was only at the beginning of the 4th century BC, however, that the principal types of classical Greek higher education became organized on definitive lines. This was the result of the joint and rival efforts of the two great educators, the philosopher Plato (*c.* 428–348/347), who opened his school, the Academy, probably in 387, and the orator Isocrates (436–338), who founded his school in about 390.

Platonic education

Plato was descended from a long line of aristocrats and became the most distinguished of Socrates' students. The indictment and execution of Socrates by what Plato considered an ignorant society turned him away from Athens and public life. After an absence of some 10 years, spent traveling the Mediterranean, he returned to Athens, where he founded a school of philosophy near the grove dedicated to the early hero Acadēmos and hence known as the Academy. The select band of scholars who gathered there engaged in philosophical disputations in preparation for their role as leaders. Good government, Plato believed, would only come from an educated society in which kings are philosophers, and philosophers, kings.

Plato's literary dialogues provide a comprehensive picture of his approach to education. Basically, it was built around the study of dialectic (the skill of accurate verbal reasoning), which, if pursued properly, he believed, enables misconceptions and confusions to be stripped away and the nature of underlying truth to be established. The ultimate educational quest, as revealed in the dialogues, is the search for the Good, that is, the ultimate idea that binds together all earthly existence.

Plato's educational program is set out in his most famous dialogue, *The Republic*. The world, he argued, has two aspects, the visible, or that which is perceived with the senses, and the non-visible, or the intelligible, which consists of universal, eternal forms or ideas that are apprehensible only by the mind. Furthermore, the visible realm itself is subdivided into two, the realm of appearances and that of beliefs. Human experiences of so-called reality, according to Plato, are only of visible "appearances" and from these can be derived only opinions and beliefs. Most people, he argued, remain locked in this visible world of opinion; only a select few can cross into the realm of the intelligible. Through a rigorous 15-year program of higher education devoted to the study of dialectics and mathematical reasoning, this elite ("persons of gold" was Plato's term) can attain an understanding of genuine reality, which is composed of such forms as goodness, truth, beauty, and justice. Plato maintained that only those individuals who survive this program are really fit for the highest offices of the state and capable of being entrusted with the noblest of all tasks, those of maintaining and dispensing justice.

The education of Isocrates

The rival school of Isocrates was much more down-to-earth and practical. It too aimed at a form of wisdom but of a much more practical order, based on working out commonsense solutions to life's problems. In contrast to Plato, Isocrates sought to develop the quality of grace, cleverness, or finesse rather than the spirit of geometry. The program of study that he enjoined upon his pupils was more literary than scientific. In addition to gymnastics and music, its basics included the study of the Homeric classics and an extensive study of rhetoric—consisting of five or six years of theory, analysis of the great classics, imitation of the classics, and finally practical exercises.

These two parallel forms of culture and of higher education were not totally in conflict: both opposed the cynical pragmatism of the Sophists; each influenced the other. Isocrates did promote elementary mathematics as a kind of mental training or mental gymnastics and did allow for a smattering of philosophy to illumine broad questions of human life. Plato, for his part, recognized the usefulness of the literary art and philosophical rhetoric. The two traditions appear as two species of one genus; their debate, continued in each generation, enriched classical culture without jeopardizing its unity.

Aristotelian education

Before leaving the Hellenic age, there is one other great figure to appraise—one who was a bridge to the next age since he was the tutor of the young prince who became Alexander the Great of Macedonia. Aristotle (384–322 BC), who was one of Plato's pupils and shared some of his opinions about education, believed that education should be controlled by the state and that it should have as a main objective the training of citizens. The last book of his *Politics* opens with these words:

> No one will doubt that the legislator should direct his attention above all to the education of youth. . . . The citizen should be moulded to suit the form of government under which he lives.

He shared some of Plato's misgivings about democracy; but, because he was no recluse but a man of the world acquainted with public affairs, he declared his preference for limited democracy, "polity," over other forms of government. His worldliness also led him to be less concerned with the search for ideas, in the Platonic mode, and more concerned with the observation of specific things. His urge for logical structure and classification, for systematization, was especially strong.

This systematization extended to a youth's education. In his first phase, from birth to age seven, he was to be physically developed, learning how to endure hardship. From age seven to puberty, his curriculum would include the fundamentals of gymnastics, music, reading, writing, and enumeration. During the next phase, from puberty to age 17, the student would be more concerned with exact knowledge, not only carrying on with music and mathematics but also exploring grammar, literature, and geography. Finally, in young manhood, only a few superior students would continue into higher education, developing encyclopaedic and intensely intellectual interests in the biological and physical sciences, ethics, and rhetoric, as well as philosophy. Aristotle's school, the Lyceum, was thus much more empirical than Plato's Academy.

The Hellenistic age. Alexander the Great's conquest of the Persian empire between 334 and 323 BC abruptly extended the area of Greek civilization by carrying its eastern frontier from the shores of the Aegean to the banks of the Syrdarya and Indus rivers in Central Asia. Its unity rested henceforward not so much on nationality (it incorporated and assimilated Persians, Semites, and Egyptians) nor on the political unity soon broken after the death of Alexander in 323 but on a common Greek way of life, the fact of sharing the same conception of man. This ideal was no longer social, communal in character, as had been that of the city-state; it now concerned man as an individual—or, better, as a person. This civilization of the Hellenistic age has been defined as a civilization of paideia—which eventually denoted the condition of a person achieving enlightened, mature self-fulfillment but which originally

The concept of paideia

signified education per se. The Greeks succeeded in preserving their distinctive national way of life amid this immense empire because, wherever numbers of them settled, they brought with them their own system of education for their youth, and they not only resisted being absorbed by the "barbarian" non-Hellenic peoples but succeeded somewhat in spreading Greek culture to many of the alien elite. It is important to note that, although Hellenism was finally to be swept away in the Middle East by the Persian national renaissance and the invasions originating from Central Asia beginning in the 2nd century BC, it continued to flourish and even expand in the Mediterranean world under Roman domination. Hellenistic civilization and its educational pattern were prolonged to the end of antiquity and even beyond; it was to be a slow metamorphosis and not a brutal revolution that would later give birth to the civilization and education strictly called Byzantine.

The institutions. Hellenistic education comprised an ensemble of studies occupying the young from age seven to age 19 or 20. To be sure, this entire program was completed only by a minority, recruited from the rich aristocratic and urban bourgeois classes. The students were mostly boys (girls occupied only a very modest place), and of course they were usually free citizens (masters, though some slaves were given a professional education occasionally reaching a high level).

As in the preceding era, education continued to be dependent upon the city, which remained the primary frame of Greek life. To facilitate control of his empire, Alexander had commenced the process of founding a network of cities or communities organized and administered in the Greek manner. In effect, the creation of vast kingdoms did not eliminate the role of the city, even if the latter was not altogether independent; the Hellenistic state was not at all totalitarian and sought to reduce its administrative machinery to a minimum. It relied upon the cities to assume responsibility for public services, that of education in particular. The city in turn looked to the contributions of the richest and most generous private individuals, either by requiring them to fill magistracies and supply costly services or by appealing to their voluntary generosity; the proper functioning of the Hellenistic city presupposed the willing contributions of "benefactors." Thus, certain educational institutions were supported—and in fact sometimes set up—by private foundations that specified exactly the use to be made of the income from their gift of capital. Many schools were private, the role of the city being limited to inspections and to the organization of athletic and musical competitions and festivals.

Physical education. The Hellenistic school par excellence was still the school of gymnastics, the practice of athletic sports and the nudity that they required being the most characteristic feature contrasting the Greek way of life with that of the barbarians. There were, at least in sufficiently large cities, several gymnasiums, separately for the different age classes and on occasion for the sexes. They were essentially palaestrae, or open-air, square-shaped sports grounds, surrounded by colonnades in which were set up the necessary services: cloakrooms, washstands, training rooms, massage rooms, and classrooms. Outside there was a track for footraces, the *stadion.*

The gymnasium

The foundation of the training always consisted of the sports properly called gymnastic and field. Horsemanship remained an aristocratic privilege. Nautical sports had a very modest role—a curious thing for a nation of sailors, but the fact is the Greeks were by origin Indo-Europeans from the interior of the Eurasian continent. The other sports—ball games, hockey—were considered merely diversions or at best preparatory exercises. As the competition of professional sports grew, however, education based on sports progressively, though no doubt very slowly, lost its preeminent position. The popularity of athletic sports as spectacle endured, but educational sports moved into the background, disappearing altogether in the Christian period (in the 4th century AD) in favour of literary studies.

There was a similar progressive decline, a similar final effacement, of artistic, particularly musical, education, the other survivor from the Archaic culture. The art of music continued to flourish, but like sports it became the concern of professional practitioners and a feature of public spectacles rather than an art generally practiced in cultivated circles.

The primary school. The child from seven to 14 years of age went to the school of letters, conducted thither, as in the classical period, by the *paidagōgos,* whose role was not limited to accompanying the child; he had also to educate him in good manners and morals and finally to act as a lesson coach. Literacy and numeration were taught in the private school conducted by the *grammatistes.* Class sizes varied considerably, from a few pupils to perhaps dozens. The teaching of reading involved an analytical method that made the process very slow. First the alphabet was taught from alpha to omega, and then backward, then from both ends at once—alpha–omega, beta–psi, and so on to mu–nu. (A comparable progression in the Latin alphabet would be *A–Z, B–Y,* and so on to *M–N.*) Then were taught simple syllables—*ba, be, bi, bo*—followed by more complex ones, and then by words, successively of one, two, and three syllables. The vocabulary list included rare words (*e.g.,* some of medical origin), chosen for their difficulty of reading and pronunciation. It took several years for the child to be able to read connected texts, which were anthologies of famous passages. With reading was associated recitation and, of course, practice in writing, which followed the same gradual plan.

The program in mathematics was very limited; rather than computation, the subject, strictly speaking, was numeration: learning the whole numbers and fractions, their names, their written notations, their representation in finger counting (in assorted bent positions of the fingers and assorted placements of either hand relative to the body). The general use of tokens and of the abacus made the teaching of methods of computation less necessary than it became in the modern world.

Secondary education. Between the primary school and the various types of higher education, the Hellenistic educational system introduced a program of intermediate, preparatory studies—a preliminary education, a kind of common trunk preparing for the different branches of higher culture, *enkyklios paideia* ("general, or common, education"). This general education, far from having "encyclopaedic" ambitions in the modern sense of the word, represented a reaction against the inordinate ambitions of philosophy and, more generally, of the Aristotelian ideals of culture, which had demanded the large accumulation of intellectual attainments. The program of the *enkyklios paideia* was limited to the common points on which, as noted earlier, the rival pedagogies of Plato and of Isocrates agreed, namely, the study of literature and mathematics. Specialized teachers taught each of these subjects. The mathematics program had not changed since the ancient Pythagoreans and comprised four disciplines—arithmetic, geometry, astronomy, and harmonics (not the art of music but the theory of the numerical laws regulating intervals and rhythm). The primary function of the *grammatikos,* or professor of letters, was to present and explicate the great classic authors: Homer first of all, of whom every cultivated man was expected to have a deep knowledge, and Euripides and Menander—the other poets being scarcely known except through anthologies. Although poetry remained the basis of literary culture, room was made for prose—for the great historians, for the orators, Demosthenes in particular, even for the philosophers. Along with these explications of texts, the students were introduced to exercises in literary composition of a very elementary character (for example, summarizing a story in a few lines).

The program of this intermediate education did not attain its definitive formulation until the second half of the 1st century BC, after the appearance of the first manual devoted to the theoretical elements of language, a slim grammatical treatise by Dionysius Thrax. The program then consisted of the seven liberal arts: the three literary arts of grammar, rhetoric, and dialectic and the four mathematical disciplines noted above. (These were, respectively, the trivium and the quadrivium of medieval education, though the latter term did not appear until the 6th century and the former not until the 9th century.) The long career of this program should not conceal the fact that in

The seven liberal arts

the course of the centuries it fell into disuse and became rather largely a theory or abstraction; in reality, literary studies gradually took over at the expense of the sciences. Of the four mathematical disciplines, only one remained in favour—astronomy. And this was not merely because of its connections with astrology but primarily because of the popularity of the basic textbook used to teach it—the *Phaenomena*, a poem in 1,154 hexameters by Aratus of Soli—whose predominantly literary quality was suited to textual explications. Not until about the 3rd and 4th centuries AD was the need of a sound preparatory mathematical education again recognized and put into practice.

Higher education. Higher education appeared in several forms, complementary or competitive. First was the *ephebeia* ("youth" culture), a kind of civic and military training that completed the education of the young Greek and prepared him to enter into life; it lasted two years (from 18 to 20) and corresponded quite closely to the obligatory military service of modern states. It was a survival from the regime of the old Greek city-states, but in the Hellenistic age the absence of national independence erased all reason for this military training; between the 3rd and 2nd centuries BC the Athenian *ephebeia* (eventually reduced to a single year) was transformed into a leisured civilian college where a minority of rich young men came to be initiated into the refinements of the elegant life. Military training came to play only a modest role and gave way to athletic competition. To this were added lectures on scientific and literary subjects, assuring the ephebe a polish of general culture. The same evolution took place in other cities: the *ephebeia* became everywhere more aristocratic than civic, more sporting than military. What the Greeks, especially those who had emigrated to the barbarian lands, demanded of it was above all that it initiate their sons into Greek life and its characteristic customs, beginning with athletic sports. Especially in Egypt, it was intended to legitimize the privileged status of the Hellene relative to the "native" Egyptian. In any event, the *ephebeia* no longer was the setting for the highest forms of education.

Education in science and medicine

Formal education in science also lacked any institutionalization. There were, however, some establishments having scientific staffs of high competence, of which the most important was the Mouseion (Museum) established at Alexandria, richly endowed by the Ptolemies; but, at least initially, it was an institute for advanced research. If the scholars endowed there were also teachers, this meant only that they dispensed instruction to a small circle of chosen disciples. The same informal character of personal training was to be seen in all the special disciplines—medicine, for example, which saw such a fine development between the time of Hippocrates (5th century BC) and that of Galen (2nd century AD). If there were in the Hellenistic era certain "schools" of medicine—old (Cnidus, Cos) and new (Pergamum, Alexandria)—these were less the equivalent of today's medical faculties than simply centres to which the presence of numerous qualified masters attracted a large number of aspirants. Whatever theory these "students" were able to learn, they learned largely through self-training and practice, by associating themselves with a practicing physician whom they accompanied to the bedsides of patients, taking part in his consultations, profiting by his experience and advice.

Philosophy and rhetoric were subjects of education most highly institutionalized. Although philosophy was taught privately by individual masters-lecturers, who could be either itinerants or residents of one place, these teachers were well organized and, in groups, possessed a kind of institutional character. On the model of Plato's Academy, the new Athenian schools of philosophy—Aristotle's Lyceum, Epicurus' Garden, the Porch (stoa), which gave its name to the Stoics—were brotherhoods in which the posts in both teaching and administration were passed from generation to generation as a kind of heritage. It was in philosophy that the personalistic character of the Hellenistic era most clearly asserted itself, in contrast to the more communal idea of the preceding period; when philosophy turned to the problem of politics, for instance, it dealt less with the citizens of a republic and more with the sovereign king, his duties and character. The central problem was henceforth that of wisdom, of the purpose that man should set for himself in order to attain happiness, the supreme ideal. The teaching of philosophy was not entirely contemplative: it involved the disciple in an experience analogous to a religious conversion, a decision implying a revision of his life and the adoption of a generally ascetic way of life. Such a vocation, however, could obviously appeal only to a moral, intellectual, and financially secure elite; philosophers were always quite a small number within the Hellenistic (and Roman) intelligentsia.

The prestige of rhetoric

The reigning discipline was always rhetoric. The prestige of the oratorical art outlived those social conditions that had inspired it; political eloquence operated only in the context of an embassy coming to plead the cause of a particular city or pressure group at the court of the sovereign. Legal eloquence maintained its function, and the profession of advocate retained its attractiveness; but it was above all the eloquence of showy set speeches, the art of the lecturer, that experienced a curious blossoming. Also, as a result of the customary habit of reading aloud, there was no sharp line between speech and the book; thus, eloquence imposed its rule upon all literary genres—poetry, history, philosophy. Even the astronomer and the physician became lecturers.

Hence, great importance was attached to the teaching of rhetoric, which developed from century to century with an ever more rigorous technicalism, precision, and systematization. The study of rhetoric had five parts: invention (the art of finding ideas, according to standard schemes), disposition (the arrangement of words and sentences), elocution, mnemonics (memory training), and action. Action was the art of self-presentation, the regulation of voice and delivery, and above all the art of reinforcing the word with the expressive power of gesture. Each of these parts, equally systematized to the tiniest detail, was taught with a technical vocabulary of extreme precision. Such an education, which in addition to theory comprised a study of the great examples to be imitated and exercises in practical application, required many years of study; in fact, even in maturity, the cultivated Hellene continued to deepen his knowledge of the art, to drill himself, to "declaim."

A rivalry existed between philosophy and rhetoric, each trying to draw into its orbit the best and the most students. Even in the time of Plato and Isocrates, this rivalry did not proceed without mutual concessions and reciprocal influences, but it remained one of the most constant characteristics of the classical tradition and continued until the end of antiquity and beyond. The long summer of Hellenic civilization was extended under the Roman domination; the great centres of learning also experienced a long prosperity. Athens in particular was the unchallenged capital of philosophy; its *ephebeia* welcomed foreigners to come to crown their culture in the "school of Greece." Its masters of eloquence also had a solid reputation, even though they had competition from such schools of Asia Minor as those of Rhodes (in the 1st century BC) and Smyrna (in the 2nd century AD). Under the later Roman Empire, Alexandria, already famous for medicine, competed with Athens for preeminence in philosophy. Other great centres developed: Beirut, Antioch, and the new capital Constantinople. The quality of the teachers and the number of students attending permits one to apply to these centres, without too much anachronism, the modern designation of "universities," or institutions of advanced learning.

ANCIENT ROMANS

Early Roman education. The quality of Latin education before the 6th century BC can only be conjectured. Rome and Roman civilization were then dominated by a rural aristocracy of landed proprietors directly engaged in exploiting their lands, even after the establishment of the republic. Their spirit was far removed from Greece and Homeric chivalry; ancient Roman education was instead an education suitable for a rural, traditional people—instilling in youth an unquestioned respect for the customs of the ancestors: the *mos maiorum*.

Education had a practical aspect, involving instruction in such farm management concerns as how to oversee the work of slaves and how to advise tenant farmers or one's

steward. It had a legal aspect; in contrast to Athenian law, which relied more on common law than on codified law, Roman justice was much more formalistic and technical and demanded much more study on the part of the citizen. Education also had a moral aspect, aiming at inculcating rural virtues, a respect for good management of one's patrimony, and a sense of austerity and frugality. Roman education, however, did not remain narrowly utilitarian; it broadened in urban Rome, where there developed the same ideal of communal devotion to the public weal that had existed in Greece—with the difference that in Rome such devotion would never be called into question. The interests of the state constituted the supreme law. The ideal set before youth was not that of the chivalrous hero in the Homeric manner but that of the great men of history who, in difficult situations, had by their courage and their wisdom saved the fatherland when it was in danger. A nation of small farmers, Rome was also a nation of soldiers. Physical education was oriented not toward self-realization or competitive sport but toward military preparedness: training in arms, toughening of the body, swimming across cold and rapid streams, and horsemanship, involving such performances as mounted acrobatics and cavalry parades under arms.

The familial character of Roman education

Differing from the Greeks, the Romans considered the family the natural milieu in which the child should grow up and be educated. The role of the mother as educator extended beyond the early years and often had lifelong influence. If, in contrast to the girl, the boy at seven years of age was allowed to move away from her exclusive direction, he came under the control of his father; the Roman father closely supervised the development and the studies of his son, giving him instruction in an atmosphere of severity and moral exigency, through precept but even more through example. The young Roman noble accompanied his father as a kind of young page in all his appearances, even within the Senate.

Familial education ended at 16, when the adolescent male was allowed to wear adult dress, the pure white woolen toga virilis. He devoted one year to an apprenticeship in public life, no longer at his father's side but placed in the care of some old friend of the family, a man of politics laden with years and honours. Then came military service, first as a simple soldier (it was well for the future leader to learn first to obey), encountering his first opportunity to distinguish himself by courage in battle, but soon thereafter as a staff officer under some distinguished commander. Civil and military, the education of the young Roman was thus completed in the entourage of some high personage whom he regarded with respect and veneration, without ceasing, however, to gravitate toward the family orbit. The young Roman was brought up not only to respect the national tradition embodied in the example of the illustrious men of the past but also, very specifically, to respect the particular traditions of his own family, which too had had its great men and which jealously transmitted a stereotype, a specific attitude toward life. If ancient Greek education can be defined as the imitation of the Homeric hero, that of ancient Rome took the form of imitation of one's ancestors.

Roman adoption of Hellenistic education. Something of these original characteristics was to survive always in Roman society, so ready to be conservative; but Latin civilization did not long develop autonomously.

It assimilated, with a remarkable faculty for adaptation, the structures and techniques of the much further evolved Hellenistic civilization. The Romans themselves were quite aware of this, as evidenced by the famous lines of Horace: "Captive Greece captivated her rude conqueror and introduced the arts to rustic Latium" ("Graecia capta ferum victorem cepit et artis intulit agresti Latio" [*Epistles*, II, i, 156]).

Greek influence was felt very early in Roman education and grew ever stronger after the long series of gains leading to the annexation of Macedonia (168 BC), of Greece proper (146 BC), of the kingdom of Pergamum (133 BC), and finally of the whole of the Hellenized Orient. The Romans quickly appreciated the advantages they could draw from this more mature civilization, richer than their own national culture. The practical Romans grasped the advantages to be drawn from a knowledge of Greek, an international language known to many of their adversaries, soon to be their Oriental subjects, and grasped the related importance of mastering the art of oratory so highly developed by the Greeks. Second-century Rome assigned to the spoken word, particularly in political and legal life, as great an importance as had Athens in the 5th century. The Roman aristocrats quickly understood what a weapon rhetoric could be for a statesman.

Rome doubly adopted Hellenistic education: on the one hand, it came to pass that a Roman was considered truly cultivated only if he had the same education, in Greek, as a native Greek acquired; on the other hand, there progressively developed a parallel system of instruction that transposed into Latin the institutions, programs, and methods of Hellenistic education. Naturally, only the children of the ruling class had the privilege of receiving the complete and bilingual education. From the earliest years, the child, boy or girl, was entrusted to a Greek servant or slave and thus learned to speak Greek fluently even before being able to speak Latin competently; the child also learned to read and write in both languages, with Greek again coming first. (Alongside this private tutoring there soon developed, from the 3rd century BC, a Greek public education in schools aimed at a socially broader clientele, but the results of this schooling were less satisfactory than the direct method enjoyed by the children of the aristocracy.) In following the normal course of studies, the young Roman was taught next by an instructor of Greek letters (*grammatikos*) and then by a Greek rhetorician. Those desiring more complete training did not content themselves with the numerous and often highly qualified Greeks to be found in Rome itself but went to Greece to participate in the higher studies of the Greeks themselves. From 119 or 118 BC onward, the Romans secured admission to the Ephebic College at Athens, and in the 1st century BC such young Latins as Cicero were attending the schools of the best philosophers and rhetoricians at Athens and Rhodes.

The tutoring of Roman children

Roman modifications. The adoption of Hellenistic education did not proceed, however, without a certain adaptation to the Latin temperament: the Romans showed a marked reserve toward Greek athleticism, which shocked both their morals and their sense of the deep seriousness of life. Although gymnastic exercises entered into their daily life, it was under the category of health and not that of sport; in Roman architecture, the palaestra or gymnasium was only an appendage of the public baths, which were exaggerations of their Greek models. There was the same reserve, on grounds of moral seriousness, toward music and dance, arts suitable for professional performers but not for freeborn young men and least of all for young aristocrats. The musical arts indeed became integrated into Latin culture as elements of the life of luxury and refinement, but as spectacle rather than as amateur participation; hence their disappearance from programs of education. It must be remembered, however, that athletics and music were in Greece itself survivals of archaic education and had already entered upon a process of decline.

This education in a foreign language was paralleled by a course of studies exactly patterned upon those of the Greek schools but transposed into the Latin language. The aristocracy was to remain always attached to the idea of private education conducted within the family, but social pressure brought about the gradual development of public education in schools, as in Greece, at three levels—elementary, secondary, and higher; they appeared at different dates and in various historical contexts.

Roman primary and secondary education

Education of youth. The appearance of the first primary schools is difficult to date; but the use of writing from the 7th century BC implies the early existence of some kind of appropriate primary instruction. The Romans took their alphabet from the Etruscans, who had taken theirs from the Greeks, who had taken theirs from the Phoenicians. The early Romans quite naturally copied the pedagogy of the Hellenistic world: the same ignorance of psychology, the same strict and brutal discipline, the same analytical method characterized by slow progress—the alphabet (forward, backward, from both ends toward the middle),

the syllabary, isolated words, then short sentences (one-line moral maxims), finally continuous texts—the same method for writing, and the same numeration, rather than computation.

It was only between the 3rd and the end of the 1st century BC that Latin secondary education developed, staffed by the *grammaticus Latinus,* corresponding to the Greek *grammatikos.* Since the principal object of this education was the explication of poetry, its rise was hindered by the slowness with which Latin literature developed. The first-known of these teachers, Livius Andronicus, took as his subject matter his own Latin translation of the *Odyssey;* two generations later, Ennius explicated his own poetic works. Only with the great poets of the age of Augustus could Latin literature provide classics able to rival Homer in educational value; they were adopted as basic texts almost immediately after their appearance. Thereafter, and until the end of antiquity, the program was not to undergo further change, the principal authors being first of all Virgil, the comic author Terence, the historian Sallust, and the unchallenged master of prose, Cicero. The methods of the Latin grammarian were copied directly from those of his Greek counterpart; the essential point was the explication of the classic authors, completed by a theoretical study of good language using a grammar textbook and by practical exercises in composition, graduated according to a minutely regulated progression and always remaining rather elementary. Theoretically, the curriculum remained that of the seven liberal arts, but, as in Greece, it practically neglected the study of the sciences in favour of that of letters.

Latin rhetoric

It was only in the 1st century BC that the teaching of rhetoric in Latin was established: the first recorded Latin rhetorician, Plotius Gallus, appeared in 93 BC in a political context, namely, as a democratic initiative to counter the aristocratic education given in Greek, and, as such, was soon prohibited by the conservative party in power. It was not until the end of the century and the appearance of the works of Cicero that this education would be revived and become normal practice; first, Cicero's discourses offered the young Latin the equivalent of those of the Greek Demosthenes, and, second, Cicero's theoretical treatises provided a technical vocabulary obviating the need for Greek manuals. But this instruction was to remain always very close to its Hellenistic origins: the terminology used by Rome's greatest educator, Quintilian (*c.* AD 35–*c.* 100), is much more impregnated with Hellenism, much less Latinized, than that which Cicero had proposed. At Rome, too, rhetoric became the form of higher education enjoying the greatest prestige; as in Greece, this popularity outlived the elimination of political eloquence. More than in Greece, legal eloquence continued to flourish (Quintilian had in mind particularly the training of future advocates), but, as in the Hellenic milieu, Latin culture became predominantly aesthetic: from the beginning of the empire, the public lecture was the most fashionable literary genre, and the teaching of rhetoric was very naturally oriented toward the art of the lecturer as the crowning achievement.

Higher education. Because the oratorical art was incontestably the most popular subject of higher education, the Romans did not feel the same urgency to Latinize the other rival branches of knowledge, which interested only a small number of specialists with unusual vocations. To be sure, the philosophical work of Cicero had the same ambition as his oratorical work and proved by its existence that it was possible to philosophize in Latin, but philosophy found no successors to Cicero as rhetoric did. There was never a Latin school for philosophy. Of course, Rome did not lack philosophers, but many used Greek as their means of expression (even the emperor Marcus Aurelius); those who, like Cicero, wrote in Latin—Seneca, for example—had taken their philosophy studies in Greek. It was the same in the sciences, particularly in the medical sciences; for long, there were no medical books in Latin except encyclopaedias on a popular level.

The innovation of legal education

On the other hand, Rome created in the school of law another type of higher education—the only one that had no equivalent in Hellenistic education. The position of law in Roman life and civilization is, of course, well known. Perhaps even more than rhetoric, it offered young Romans profitable careers; very naturally, there developed an appropriate education to prepare them. At first elementary in character and entirely practical, it was given within the framework of apprenticeship: the professor of law (*magister juris*) was primarily a practitioner, who initiated into his art the group of young disciples entrusted to him; these listened to his consultations and heard him plead or judge. Beginning in Cicero's time and undoubtedly under his influence, this instruction was paralleled by a systematic theoretical exposition. Roman law was thus promoted to the rank of a scientific discipline. True schools were progressively established and took on an official character; their existence is well attested beginning with the 2nd century AD. It was at this same time that legal education acquired its definitive tools, with the composition of systematic elementary treatises such as the *Institutiones* of Gaius, manuals of procedure, commentaries on the law, and systematic collections of jurisprudence. This creative period perhaps reached its peak at the beginning of the 3rd century AD. The works of the great legal authors of this time, which became classics, were offered by the law professor with much interpretation and explication—very similar to the way in which grammarians offered literature.

Rome, the capital, remained the great centre of this advanced study in law. At the beginning of the 3rd century, however, there appeared in the Roman Orient the school of Beirut. The teaching there was in Latin; and, to hear it and profit by the advantages that it offered for a high administrative or judicial career, many young Greeks enrolled at the school, in spite of the language obstacle. Only a legal career could persuade the Greeks to learn Latin, a language that they had always regarded as "barbarous."

The Roman world became covered with a network of schools concurrent with the Romanization of the provinces. The primary school always remained private; on the other hand, many schools of grammar or rhetoric acquired the character of public institutions supported (as in the Hellenic world) either by private foundations or by a municipal budget. In effect, it was always the city that was responsible for education. The liberal central government of the high empire, anxious to reduce its administrative apparatus to a minimum, made no pretense of assuming charge of it. It was content to encourage education and to favour teaching careers by fiscal exemptions; and only very exceptionally did an emperor create certain chairs of higher education and assign them a regular stipend. Vespasian (AD 69–79) created two chairs at Rome, one of Greek rhetoric and the other of Latin rhetoric. Marcus Aurelius (AD 161–180) similarly endowed, in Athens, a chair of rhetoric and four chairs of philosophy, one for each of the four great sects—Platonism, Aristotelianism, Epicureanism, and Stoicism.

The durable character of Greco-Roman education

Education in the later Roman Empire. The dominant fact is the extraordinary continuity of the methods of Roman education throughout such a long succession of centuries. Whatever the profound transformations in the Roman world politically, economically, and socially, the same educational institutions, the same pedagogical methods, the same curricula were perpetuated without great change for 1,000 years in Greek and six or seven centuries in Roman territory. At most, a few nuances of change need be noted. There was a measure of increasing intervention by the central government, but this was primarily to remind the municipalities of their educational duties, to fix the remuneration of teachers, and to supervise their selection. Only higher education received direct attention: in AD 425, Theodosius II created an institute of higher education in the new capital of Constantinople and endowed it with 31 chairs for the teaching of letters, rhetoric (both Greek and Latin), philosophy, and law. Another innovation was that the exuberant growth of the bureaucratic apparatus under the later empire favoured the rise of one branch of technical education, that of stenography.

The only evolution of any notable extent involves the use of Greek and Latin. There had never been more than a few Greeks who learned Latin, even though the growing machinery of administration and the increasing clientele drawn to the law schools of Beirut and Constantinople

tended to increase the numerical size of this tiny minority. On the other hand, in Latin territory, late antiquity exhibited a general recession in the use of Greek. Although the ideal remained unchanged and high culture always proposed to be bilingual, most people generally knew Greek less and less well. This retrogression need not be interpreted solely as a phenomenon of decadence: it had also a positive aspect, being an effect of the development of Latin culture itself. The richness and worth of the Latin classics explain why the youth of the West had less time than formerly to devote to the study of the Greek authors. Virgil and Cicero had replaced Homer and Demosthenes, just as in modern Europe the ancient languages have retreated before the progress of the national languages and literatures. Hence, in the later empire there appeared specialists in intercultural relations and translations from Greek into Latin. In the 4th and particularly in the 5th century, medical education in Latin became possible, thanks to the appearance of a whole medical (and veterinary) literature consisting essentially of translations of Greek manuals. It was the same with philosophy: resuming Cicero's enterprise at a distance of more than five centuries, Boethius (*c.* 480–524) in his turn sought with his manuals and his translations to make the study of that discipline available in Latin. Although the misfortunes of Italy in the 6th century, including the Lombardian invasion, did not permit this hope to be realized, the work of Boethius later nourished the medieval renaissance of philosophic thought.

Christian use of Greco-Roman education

Nothing better demonstrates the prestige and the allure of classical culture than the attitude taken toward it by the Christians. This new religion could have organized an original system of education analogous to that of the rabbinical school—that is, one in which children learned through study of the Holy Scriptures—but it did not do so. Usually, Christians were content to have both their special religious education, provided by the church and the family, and their classical instruction, received in the schools and shared with the pagans. Thus, they maintained the tradition of the empire after it had become Christian. Certainly, in their view, the education dispensed by these schools must have presented many dangers, inasmuch as classical culture was bound up with its pagan past (at the beginning of the 3rd century the profession of schoolteacher was among those that disqualified one from baptism); but the utility of classical culture was so evident that they considered it necessary to send their children to these same schools in which they barred themselves from teaching. From Tertullian to St. Basil the Great of Caesarea, Christian scholars were ever mindful of the dangers presented by the study of the classics, the idolatry and immorality that they promoted; nevertheless, they sought to show how the Christian could make good use of them.

With the passage of time and the general conversion of Roman society and particularly of its ruling class, Christianity, overcoming its reserve, completely assimilated and took over classical education. In the 4th century Christians were occupying teaching positions at all levels, from schoolmasters and grammarians to the highest chairs of eloquence. In his treatise *De doctrina Christiana* (426), St. Augustine formulated the theory of this new Christian culture: being a religion of the Book, Christianity required a certain level of literacy and literary understanding; the explication of the Bible required the methods of the grammarian; preaching a new field of action required rhetoric; theology required the equipment of philosophy. The synthesis of Christianity and classical education had become so intimate that, when the "barbarian" invasions swept away the traditional school along with many other imperial and Roman institutions, the church, needing a literary culture for the education of its clergy, kept alive the cultural tradition that Rome had received from the Hellenistic world. (H.-I.M./J.Bo.)

Education in Persian, Byzantine, early Russian, and Islāmic civilizations

ANCIENT PERSIA

The ancient Persian empire began when Cyrus II the Great initiated his conquests in 559 BC, and it ended when it was overrun by the Muslims in AD 651. Three elements dominated this ancient Persian civilization: (1) a rigorous and challenging physical environment, (2) the activist and positive Zoroastrian religion and ethics, and (3) a militant, expansionist people. These elements developed in the Persians an adventurous personality mingled with intense national feelings.

Zoroastrian influences

In the early period (559–330 BC), known as the Achaemenid period for the dynastic name of Cyrus and his successors, education, sustained by Zoroastrian ethics and the requirements of a military society, aimed at serving the needs of four social classes—priests, warriors, tillers of the soil, and merchants. Three principles sustained Zoroastrian ethics: the development of good thoughts, of good words, and of good actions (see ZOROASTRIANISM AND PARSIISM). Achaemenid-Zoroastrian education stressed strong family ties and community feelings, acceptance of imperial authority, religious indoctrination, and military discipline.

Education was a private enterprise. Formative education was carried on in the home and continued after the age of seven in court schools for children of the upper classes. Secondary and higher education included training in law to prepare for government service, as well as medicine, arithmetic, geography, music, and astronomy. There were also special military schools.

In 330 BC Persia was conquered by Alexander the Great, and native Persian or Zoroastrian education was largely eclipsed by Hellenistic. Greek practices continued during the Parthian empire (247 BC–AD 224), founded by semi-nomadic conquerors from the Caspian steppes. And, thus, truly Persian influences were not restored until the appearance of a new, more sophisticated and reform-minded dynasty, the Sāsānians, in the 3rd century AD. In what has been called the neo-Persian empire of the Sāsānians (AD 224–651), the Achaemenid social structure and education were revived and further developed and modified. Zoroastrian ethics, though more advanced than during the Achaemenid period, emphasized similar moral principles but with new stress upon the necessity for labour (particularly agriculture), upon the sanctity of marriage and family devotion, and upon the cultivation of respect for law and of intellectualism—all giving to education a strong moral, social, and national foundation. The subject matter of basic education included physical and military exercises, reading (Pahlavi alphabet), writing (on wooden tablets), arithmetic, and the fine arts.

The Academy of Gondēshāpūr

The greatest achievement of Sāsānian education was in higher education, particularly as it developed in the Academy of Gondēshāpūr. Here, Zoroastrian culture, Indian and Greek sciences, Alexandrian-Syrian thought, medical training, theology, philosophy, and other disciplines developed to a high degree, making Gondēshāpūr the most advanced academic centre of learning in the later period of Sāsānian civilization. The academy, to which came students from various parts of the world, advanced, among other subjects, Zoroastrian, Greek, and Indian philosophies; Persian, Hellenic, and Indian astronomy; Zoroastrian ethics, theology, and religion; law, government, and finance; and various branches of medicine.

It was partly through the Academy of Gondēshāpūr that important elements of classical Greek and Roman learning reached the Muslims during the 8th and 9th centuries AD and through them, in Latin translations of Arabic works, the Schoolmen of western Europe during the 12th and 13th centuries. (M.K.N.)

THE BYZANTINE EMPIRE

The Byzantine Empire was a continuation of the Roman Empire in the eastern Mediterranean area after the loss of the western provinces to Germanic kingdoms in the 5th century. Although it lost some of its eastern lands to the Muslims in the 7th century, the empire lasted until Constantinople—the new capital founded by the Roman emperor Constantine the Great in 330—fell to the Ottoman Turks in 1453. The empire was seriously weakened in 1204 when, as a result of the Fourth Crusade, its lands were partitioned and Constantinople captured; but until then it remained a powerful centralized state, with a

common Christian faith, an efficient administration, and a shared Greek culture. This culture, already Christianized in the 4th and 5th centuries, was maintained and transmitted by an educational system that was inherited from the Greco-Roman past and based on the study and imitation of classical Greek literature.

Stages of education. There were three stages of education. The basic skills of reading and writing were taught by the elementary-school master, or *grammatistes,* whose pupils generally ranged from six or seven to 10 years of age. The secondary-school master, or *grammatikos,* supervised the study and appreciation of classical literature and of literary Greek, from which the spoken Greek of everyday life differed more and more in the course of time, and Latin (until the 6th century). His pupils ranged in age from 10 to 15 or 16. Next, the rhetorician, or *rhētor,* taught pupils how to express themselves with clarity, elegance, and persuasiveness, in imitation of classical models. Speaking style was deemed more important than content or original thinking. An optional fourth stage was provided by the teacher of philosophy, who introduced pupils to some of the topics of ancient philosophy, often by reading and discussing works of Plato or Aristotle. Rhetoric and philosophy formed the main content of higher education.

Availability of education

Elementary education was widely available throughout most of the empire's existence, not only in towns but occasionally in the countryside as well. Literacy was therefore much more widespread than in western Europe, at least until the 12th century. Secondary education was confined to the larger cities. Pupils desiring higher education had almost always to go to Constantinople, which became the cultural centre of the empire after the loss to the Muslim Arabs of Syria, Palestine, and Egypt in the 7th century. Monasteries sometimes had schools in which young novices were educated, but they did not teach lay pupils. Girls did not normally attend schools, but the daughters of the upper classes were often educated by private tutors. Many women were literate, and some, such as the hymnographer Kasia (9th century) and the historian-princess Anna Comnena (1083–*c.* 1153), were recognized as writers of distinction.

Elementary education. Elementary-school pupils were taught to read and write individual letters first, then syllables, and finally short texts, often passages from the Psalms. They probably also learned simple arithmetic at this stage. Teachers had a humble social status and depended on the fees paid by parents for their livelihood. They usually held classes in their own homes or on church porches but were sometimes employed as private tutors by wealthy households. They had no assistants and used no textbooks. Teaching methods emphasized memorization and copying exercises, reinforced by rewards and punishments.

Secondary education. The secondary-school teacher taught the grammar and vocabulary of classical and ecclesiastical Greek literature from the Hellenistic and Roman periods and explained the elements of classical mythology and history that were necessary for the study of a limited selection of ancient Greek texts, mainly poetry, beginning with Homer. The most commonly used textbook was the brief grammar by Dionysius Thrax; numerous and repetitive later commentaries on the book were also frequently used. From the 9th century on, these books were sometimes supplemented with the *Canons* of Theognostos, a collection of brief rules of orthography and grammar. The *grammatikos* might also make use of anonymous texts dating from late antiquity, which offered word-by-word grammatical explanations of Homer's *Iliad,* or of similar texts on the Psalms by Georgius Choiroboscos (early 9th century). Pupils would not normally possess copies of these textbooks, since handwritten books were very expensive, but would learn the rules by rote from their teacher's dictation. Beginning in the 11th century, much use was made in secondary education of *schedē* (literally, "sketches" or "improvisations"), short prose texts that often ended in a few lines of verse. These were specially written by a teacher to illustrate points of grammar or style. From the early 14th century on, much use was also made of *erotemata,* systematic collections of questions and answers on grammar which the pupil learned by heart.

Secondary schools often had more than one teacher, and the older pupils were often expected to help teach their juniors. Schools of this kind had little institutional continuity, however. The most lasting schools were those conducted in churches.

Higher education. The rhetorician's textbooks included systematic handbooks of the art of rhetoric, model texts with detailed commentaries, and specimens of oratory by classical or postclassical Greek writers and by Church Fathers, in particular Gregory of Nazianzus. Many Byzantine handbooks of rhetoric survive from all periods. They are often anonymous and always derivative, mostly based directly or indirectly on the treatises of Hermogenes of Tarsus (late 2nd century AD). There is little innovation in the theory of rhetoric that they expound. After studying models, pupils went on to compose and deliver speeches on various general topics.

Until the early 6th century there was a flourishing school of Neoplatonic philosophy in Athens, but it was repressed or abolished in 529 because of the active paganism of its professors. A similar, but Christian, school in Alexandria survived until the Arab conquest of Egypt in 640. For the next five centuries philosophical teaching seems to have been limited to simple surveys of Aristotle's logic, but in the 11th century there was a renewal of interest in the Greek philosophical tradition and many commentaries on works of Aristotle were composed, evidently for use in teaching. In the early 15th century the philosopher George Gemistos Plethon revived interest in Plato, who until then had been neglected for Aristotle. All philosophical teaching in the Byzantine world was concerned with the explanation of texts rather than with the analysis of problems.

State and church patronage of education

Because higher education provided learned and articulate personnel for the sophisticated bureaucracies of state and church, it was often supported and controlled officially, although private education always existed as well. There were officially appointed teachers in Constantinople in the 4th century, and in 425 the emperor Theodosius II established professorships of Greek and Latin grammar, rhetoric, and philosophy, but these probably did not survive the great crisis of the Arab and Slav invasions of the 7th century. In the 9th century the School of Magnaura, an institution of higher learning, was founded by imperial decree. In the 11th century Constantine IX established new schools of philosophy and law at the Capitol School in Constantinople. Both survived until the 12th century, when the school under the control of the patriarch of Constantinople, with teachers of grammar, rhetoric, and biblical studies, gained predominance. After the interval of Western rule in Constantinople (1204–61), both emperors and patriarchs gave sporadic support to higher education in the capital. As the power, wealth, and territory of the empire were eroded in the 14th and 15th centuries, the church became the principal and ultimately the only patron of higher education.

Professional education. Teaching of such professional subjects as medicine, law, and architecture was largely a matter of apprenticeship, although at various times there was some imperially supported or institutionalized teaching.

Strangely, there is little sign of systematic teaching of theology, apart from that given by the professors of biblical studies in the 12th-century patriarchal school. Studious reading of works by the Church Fathers was the principal path to theological knowledge in Byzantium, both for clergy and for laymen. Nonetheless, religious orthodoxy, or faith, was Byzantium's greatest strength. It held the empire together for more than 1,000 years against eastern invaders. Faith was also the Byzantine culture's chief limitation, choking originality in the sciences and the practical arts. But within this limitation it preserved the literature, science, and philosophy of classical Greece in recopied texts, some of which escaped the plunders of the crusaders and were carried to southern Italy, restoring Greek learning there. Combined with the treasures of classical learning that reached Europe through the Muslims, this Byzantine heritage helped to initiate the beginnings of the European Renaissance.

(M.K.N./R.B.)

EARLY RUSSIAN EDUCATION: KIEV AND MUSCOVY

Properly, the term Russia applies only to the empire that covered roughly the present area of the Soviet Union from the 18th to the early 20th century. It is sometimes less strictly employed, however, as in this section, to refer to that area from ancient times as well.

Early influences on Russian education and culture

The influences of the Byzantine Empire and of the Eastern Orthodox church made themselves strongly felt in Russia as early as the 10th century, when Kiev, the first East Slavic state, was firmly established. At that time Prince Svyatoslav, a determined pagan, failed to maintain control of the route "from the Varangians to the Greeks" (south from Novgorod through Kiev, along the Dnepr River) and the Byzantine Empire expelled him from its Balkan possessions, which he was attempting to conquer. After his death in 972 the way lay open for sustained penetration of cultural influences emanating from Byzantium into the Kievan state, although formal relations between the two powers were seldom harmonious. Byzantine cultural materials entering the Kievan state were translated into Old Church Slavonic; thus, there was no language barrier. A famous tale in an early chronicle recounts how Grand Prince Vladimir in 988 ordered the people of Kiev to receive baptism in the Orthodox Christian rite. It is, however, highly dubious to claim that this event, which established Christianity as the predominant cultural force in the Kievan state, also marked the beginning of an institutionalized system of education. A few sources of the time spoke of "book learning," but all this actually meant was that people were expected to be acquainted with the rudiments of Holy Writ.

The next epoch in Russian history is known as the appanage period. This period runs roughly from the decline of Kiev in the 11th century to the rise of the grand principality of Moscow (Muscovy) in the 14th century. It was characterized by the appearance of numerous autonomous fiefdoms and a population shift from southern plains to northern forests, brought about in large part by attacks from steppe nomads. Although the church and monasteries continued to acquire wealth and property, anarchic decentralization was not conducive to the development of any kind of widespread, uniform educational apparatus.

During this time of instability, in 1240, the Mongol (or Tatar) empire, known as the Golden Horde, sacked and devastated the European Russian Plain and imposed its control over the region, although with diminishing efficiency, until 1451. The Mongol rule had a debilitating effect on all phases of Russian culture, including the church, which became more formalistic and ritualistic. What little can be learned about education at this time must be culled from later biographies of contemporary saints. It is not clear who served as teachers, how many there were, where they taught, or how many and what kind of pupils they had. What instruction they gave was of an uncompromisingly religious nature: seven-year-olds did little more than read aloud and chant devotional materials or, very rarely, recite the numbers from one to 100. Because students uttered their assignments simultaneously, the result was often chaotic.

By the time the Mongol rule came to an end, the welter of independent Russian principalities had been united under the authority of the grand principality of Moscow, which began a successful program of territorial expansion. Controversies over religious issues, particularly the respective roles of church and state, flared up but failed to bring about any real improvement in education. The church's inability to provide adequate education was recognized, however, and in 1551 a church council known as the Hundred Chapters was convened at the initiative of the tsar Ivan IV the Terrible. The council heard many stories of clerical ignorance and licentiousness, and its deliberations made it clear that no effective system or institution existed to educate the clergy, the key class in the cultural establishment.

The familial character of Russian education

It is misleading to think of education solely in institutional terms, however. Another system existed in early Russia: the highly developed family system, within which from generation to generation parents handed on to their children skills and knowledge. Indeed, the very strength and tenacity of the family unit may well have retarded development of a more formal educational structure.

Things began to change in the 17th century. It is necessary to bear in mind that Kiev and much of the western Ukraine had for centuries been under the control of the Roman Catholic Polish-Lithuanian state, where intellectual achievement and ferment, especially during the Renaissance and Reformation, had been considerably greater than in Muscovite Russia. The people of the Ukraine were determined to preserve Orthodoxy from Catholic pressure, which grew intense when the Jesuits employed their excellent schools as one means to spearhead the Counter-Reformation. Different Orthodox groups responded to the challenge by forming schools at many levels, culminating in the foundation of the Kievan Academy by Peter Mogila, the energetic metropolitan of Kiev, who strove to adapt Western educational techniques to defend Orthodoxy. It should be noted, however, that, although these schools adopted portions of the broader Western curriculum, their goal continued to be what it always had been, the inculcation of traditional religious values.

By the mid-17th century much of the western Ukraine had come under Muscovite control, enabling a number of educated Ukrainians, some trained in Poland, a few even in Rome, to come to Moscow. They arrived under the auspices of Patriarch Nikon, who was then engaged in correcting what he saw as errors in Orthodox church books; but their appearance aroused deep suspicion on the part of the Orthodox establishment, many of whose members displayed little interest in or sympathy for the establishment of schools, an undertaking the newcomers considered to be of primary importance. Educational reforms nevertheless continued, albeit slowly.

The reign of Peter I the Great (1682–1725) ushered in a new and more dynamic age, although even this ruler's reforming zeal proved inadequate to the central task of creating a national school system, particularly at the elementary level. Religion was deemphasized as Peter strove to establish at least a few institutions that would provide graduates trained in practical subjects for government and military service. Church schools were brought under state control, and the Academy of Sciences was established. Nevertheless, the creation of a network of schools capable at all levels of responding to Russia's rapidly changing priorities was a task that awaited the future. (H.F.Gr.)

THE ISLĀMIC ERA

The Muslim blend of scholastic heritages

Influences on Muslim education and culture. The Greco-Byzantine heritage of learning that was preserved through the medium of Middle Eastern scholarship was combined with elements of Persian and Indian thought and taken over and enriched by the Muslims. It was initiated as early as the Umayyad caliphate (661–750), which allowed the sciences of the Hellenistic world to flourish in Syria and patronized Semitic and Persian schools in Alexandria, Beirut, Gondēshāpūr, Nisibis, Haran, and Antioch. But the largest share of Islām's preservation of classical culture was assumed by the 'Abbāsid caliphate (750–*c.* 1100), which followed the Umayyad and encouraged and supported the translation of Greek works into Arabic, often by Nestorian, Hebrew, and Persian scholars. These translations included works by Plato and Aristotle, Hippocrates, Galen, Dioscorides, Alexander of Aphrodisias, Ptolemy, and others. The great mathematician al-Khwārizmī (flourished 9th century) compiled astronomical tables, introduced Hindu numerals (which became Arabic numerals), formulated the oldest known trigonometric tables, and prepared a geographic encyclopaedia in cooperation with 69 other scholars.

The transmission of classical culture through Muslim channels can be divided into seven basic types: works translated directly from Greek into Arabic; works translated into Pahlavi, including Indian, Greek, Syriac, Hellenistic, Hebrew, and Zoroastrian materials, with the Academy of Gondēshāpūr as the centre of such scholarship (the works then being translated from Pahlavi into Arabic); works translated from Hindi into Pahlavi, then into Syriac, Hebrew, and Arabic; works written by Muslim scholars from the 9th through the 11th centuries but borrowed, in effect,

from non-Muslim sources, with the line of transmission obscure; works that amounted to summaries and commentaries of Greco-Persian materials; works by Muslim scholars that were advances over pre-Islāmic learning but that might not have developed in Islām had there not been the stimulation from Hellenistic, Byzantine, Zoroastrian, and Hindu learning; and, finally, works that appear to have arisen from purely individual genius and national cultures and would likely have developed independent of Islām's classical heritage of learning.

Aims and purposes of Muslim education. Islām placed a high value on education, and, as the faith spread among diverse peoples, education became an important channel through which to create a universal and cohesive social order. By the middle of the 9th century knowledge was divided into three categories: the Islāmic sciences, the philosophical and natural sciences (Greek knowledge), and the literary arts. The Islāmic sciences, which emphasized the study of the Qur'ān (the Islāmic scripture) and the Ḥadīth (the sayings and traditions of the Prophet Muḥammad) and their interpretation by leading scholars and theologians, were valued the most highly, but Greek scholarship was considered equally important albeit less virtuous.

Early Muslim education emphasized practical studies, such as the application of technological expertise to the development of irrigation systems, architectural innovations, textiles, iron and steel products, earthenware, and leather products; the manufacture of paper and gunpowder; the advancement of commerce; and the maintenance of a merchant marine. After the 11th century, however, denominational interests dominated higher learning, and the Islāmic sciences achieved preeminence. Greek knowledge was studied in private, if at all, and the literary arts diminished in significance as educational policies encouraging academic freedom and new learning were replaced by a closed system characterized by an intolerance toward scientific innovations, secular subjects, and creative scholarship. This denominational system spread throughout eastern Islām from Transoxania (roughly modern Uzbek S.S.R.) to Egypt, with some 75 schools in existence between about 1050 and 1250.

Organization of education. The system of education in the Muslim world was unintegrated and undifferentiated. Learning took place in a variety of institutions, among them the *ḥalqah,* or study circle; the *maktab* (*kuttab*), or elementary school; the palace schools; bookshops and literary salons; and the various types of colleges, the *meshed,* the *masjid,* and the madrasah. All the schools taught essentially the same subjects.

Varieties of Islāmic schools

The simplest type of early Muslim education was offered in the mosques, where scholars who had congregated to discuss the Qur'ān began, before long, to teach the religious sciences to interested adults. Mosques increased in number under the caliphs, particularly the 'Abbāsids: 3,000 of them were reported in Baghdad alone in the first decades of the 10th century; as many as 12,000 were reported in Alexandria in the 14th century, most of them with schools attached. Some mosques, such as that of al-Manṣūr, built during the reign of Hārūn ar-Rashīd in Baghdad, or those in Isfahan, Mashhad, Ghom, Damascus, Cairo, and the Alhambra (Granada), became centres of learning for students from all over the Muslim world. Each mosque usually contained several study circles (*ḥalqah*), so named because the teacher was, as a rule, seated on a dais or cushion with the pupils gathered in a semicircle before him. The more advanced a student, the closer he was seated to the teacher. The mosque circles varied in approach, course content, size, and quality of teaching, but the method of instruction usually emphasized lectures and memorization. Teachers were as a rule looked upon as masters of scholarship, and their lectures were meticulously recorded in notebooks. Students often made long journeys to join the circle of a great teacher. Some circles, especially those in which the Ḥadīth was studied, were so large that it was necessary for assistants to repeat the lecture so that every student could hear and record it.

Elementary schools (*maktab,* or *kuttab*), in which pupils learned to read and write, date to the pre-Islāmic period in the Arab world. After the advent of Islām, these schools developed into centres for instruction in elementary Islāmic subjects. Students were expected to memorize the Qur'ān as perfectly as possible. Some schools also included in their curriculum the study of poetry, elementary arithmetic, penmanship, ethics (manners), and elementary grammar. *Maktab*s were quite common in almost every town or village in the Middle East, Africa, Sicily, and Spain.

Schools conducted in royal palaces taught not only the curriculum of the *maktab*s but also social and cultural studies designed to prepare the pupil for higher education, for service in the government of the caliphs, or for polite society. The instructors were called *muʾaddib*s, or instructors in good manners. The exact content of the curriculum was specified by the ruler, but oratory, history, tradition, formal ethics, poetry, and the art of good conversation were often included. Instruction usually continued long after the pupils had passed elementary age.

The high degree of learning and scholarship in Islām, particularly during the 'Abbāsid period in eastern Islām and the later Umayyads in western Islām, encouraged the development of bookshops, copyists, and book dealers in large, important Islāmic cities such as Damascus, Baghdad, and Córdoba. Scholars and students spent many hours in these bookshop schools browsing, examining, and studying available books or purchasing favourite selections for their private libraries. Book dealers traveled to famous bookstores in search of rare manuscripts for purchase and resale to collectors and scholars and thus contributed to the spread of learning. Many such manuscripts found their way to private libraries of famous Muslim scholars such as Avicenna, al-Ghazālī, and al-Fārābī, who in turn made their homes centres of scholarly pursuits for their favourite students.

Fundamental to Muslim education as were the circle schools, the *maktab*s, and the palace schools, they embodied definite educational limitations. Their curricula were limited; they could not always attract well-trained teachers; physical facilities were not always conducive to a congenial educational environment; and conflicts between religious and secular aims in these schools were almost irreconcilable. Most importantly, these schools could not meet the growing need for trained personnel or provide sufficient educational opportunities for those who wished to continue their studies. These pressures led to the creation of a new type of school, the madrasah, which became the crown and glory of medieval Muslim education. The madrasah was an outgrowth of the *masjid,* a type of mosque college dating to the 8th century. The differences between these two institutions are still being studied, but most scholars believe that the *masjid* was also a place of worship and that, unlike the madrasah, its endowment supported only the faculty and not the students as well. A third type of college, the *meshed* (shrine college), was usually a madrasah built next to a pilgrimage centre. Whatever their particularities, all three types of college specialized in legal instruction, each turning out experts in one of the four schools of Sunnite, or orthodox, Islāmic law.

Madrasahs may have existed as early as the 9th century, but the most famous one was founded in 1057 by the vizier Nizām al-Mulk in Baghdad. The Nizāmīyah, devoted to Sunnite learning, served as a model for the establishment of an extensive network of such institutions throughout the eastern Islāmic world, especially in Cairo, which had 75 madrasahs, in Damascus, which had 51, and in Aleppo, where the number of madrasahs rose from six to 44 between 1155 and 1260.

The great Muslim institutions

Important institutions also developed in the Spanish cities of Córdoba, Seville, Toledo, Granada, Murcia, Almería, Valencia, and Cádiz, in western Islām, under the Umayyads. The madrasahs had no standard curriculum; the founder of each school determined the specific courses that would be taught, but they generally offered instruction in both the religious sciences and the physical sciences.

The contribution of these institutions to the advancement of knowledge was vast. Muslim scholars calculated the angle of the ecliptic; measured the size of the Earth; calculated the precession of the equinoxes; explained, in the field of optics and physics, such phenomena as refraction of light, gravity, capillary attraction, and twilight; and

developed observatories for the empirical study of heavenly bodies. They made advances in the uses of drugs, herbs, and foods for medication; established hospitals with a system of interns and externs; discovered causes of certain diseases and developed correct diagnoses of them; proposed new concepts of hygiene; made use of anesthetics in surgery with newly innovated surgical tools; and introduced the science of dissection in anatomy. They furthered the scientific breeding of horses and cattle; found new ways of grafting to produce new types of flowers and fruits; introduced new concepts of irrigation, fertilization, and soil cultivation; and improved upon the science of navigation. In the area of chemistry, Muslim scholarship led to the discovery of such substances as potash, alcohol, nitrate of silver, nitric acid, sulfuric acid, and mercury chloride. It also developed to a high degree of perfection the arts of textiles, ceramics, and metallurgy.

The Islāmic renaissance and medieval periods

Major periods of Muslim education and learning. The renaissance of Islāmic culture and scholarship developed largely under the 'Abbāsid administration in eastern Islām and under the later Umayyads in western Islām, mainly in Spain, between 800 and 1000. This latter period, the golden age of Islāmic scholarship, was largely a period of translation and interpretation of classical thoughts and their adaptation to Islāmic theology and philosophy. The period also witnessed the introduction and assimilation of Hellenistic, Persian, and Hindu mathematics, astronomy, algebra, trigonometry, and medicine into Muslim culture.

Whereas the 8th and 9th centuries, mainly between 750 and 900, were characterized by the introduction of classical learning and its refinement and adaptation to Islāmic culture, the 10th and 11th were centuries of interpretation, criticism, and further adaptation. There followed a period of modification and significant additions to classical culture through Muslim scholarship. Then, during the 12th and 13th centuries, most of the works of classical learning and the creative Muslim additions were translated from Arabic into Hebrew and Latin. The decline of Muslim scholarship coincided with the early phases of the European intellectual awakening that these translations were partly instrumental in bringing about.

Creative scholarship in Islām from the 10th to the 12th century included works by such scholars as Omar Khayyam, al-Bīrūnī, Fakhr ad-Dīn ar-Rāzī, Avicenna (Ibn Sīnā), aṭ-Ṭabarī, Avempace (Ibn Bājjah), and Averroës (Ibn Rushd).

Influence of Islāmic learning on the West. The translation into Latin of most Islāmic works during the 12th and 13th centuries had a great impact upon the European Renaissance. As Islām was declining in scholarship and Europe was absorbing the fruits of Islām's centuries of creative productivity, signs of Latin Christian awakening were evident throughout the European continent.

The 12th century was one of intensified traffic of Muslim learning into the Western world through many hundreds of translations of Muslim works, which helped Europe seize the initiative from Islām when political conditions in Islām brought about a decline in Muslim scholarship. By 1300, when all that was worthwhile in Muslim scientific, philosophical, and social learning had been transmitted to European schoolmen through Latin translations, European scholars stood once again on the solid ground of Hellenistic thought, enriched or modified through Muslim and Byzantine efforts. (M.K.N./J.S.Sz.)

The European Middle Ages

THE BACKGROUND OF EARLY CHRISTIAN EDUCATION

From the beginnings to the 4th century. At first Christianity found most of its adherents among the poor and illiterate, making little headway, as St. Paul observed (1 Corinthians 1:26), among the worldly-wise, the mighty, and those of high rank. But during the 2nd century AD and afterward it appealed more and more to the educated class and to leading citizens. These naturally wanted their children to have at least as good an education as they themselves had had, but the only schools available were the grammar and rhetoric schools, with their Greco-Roman, non-Christian culture. There were different opinions among Christian leaders about the right attitude to this dilemma that confronted all Christians who sought a good education for their children. The Greek Fathers, especially the Christian Platonists Clement of Alexandria and Origen, sought to prove that the Christian view of the universe was compatible with Greek thought and even regarded Christianity as the culmination of philosophy, to which the way must be sought through liberal studies. Without a liberal education the Christian could live a life of faith and obedience but could not expect to attain an intellectual understanding of the mysteries of the faith or expect to appreciate the significance of the Gospel as the meeting ground of Hellenism and Judaism. St. Augustine and St. Basil also tolerated the use of the secular schools by Christians, maintaining that literary and rhetorical culture is valuable so long as it is kept subservient to the Christian life. The Roman theologian Tertullian, on the other hand, was suspicious of pagan culture, but he admitted the necessity, though deploring it, of making use of the educational facilities available.

Views of the early Christian Fathers

In any event, most Christians who wanted their children to have a good education appear to have sent their children to the secular schools; this practice continued even after 313, when the emperor Constantine, who had been converted to Christianity, stopped the persecution of Christians and gave them the same rights as other citizens. Christians also set up catechetical schools for the religious instruction of adults who wished to be baptized. Of these schools the most famous was the one at Alexandria in Egypt, which had a succession of outstanding heads, including Clement and Origen. Under their scholarly guidance, it developed a much wider curriculum than was usual in catechetical schools, including the best in Greek science and philosophy in addition to Christian studies. Other schools modeled on that at Alexandria developed in some parts of the Middle East, notably in Syria, and continued for some time after the collapse of the empire in the west.

From the 5th to the 8th century. The gradual subjugation of the Western Empire by the barbarian invaders during the 5th century eventually entailed the breakup of the educational system that the Romans had developed over the centuries. The barbarians, however, did not destroy the empire; in fact, their entry was really in the form of vast migrations that swamped the existing and rapidly weakening Roman culture. The position of the emperor remained, the barbarians exercising local control through smaller kingdoms. Roman learning continued, and there were notable examples in the writings of Boethius, chiefly his *Consolation of Philosophy.* Boethius composed most of these studies while acting as director of civil administration under the Ostrogoths. Equally famous was his contemporary Cassiodorus (*c.* 490–*c.* 585) who, as a minister under the Ostrogoths, worked energetically at his vision of *civilitas,* a program of educating the public and developing a sound administrative structure. Thus, despite the political and social upheavals, the methods and program of ancient education survived into the 6th century in the new barbarian Mediterranean kingdoms; indeed, the barbarians were frequently impressed and attracted by things Roman. In Ostrogothic Italy (Milan, Ravenna, Rome) and in Vandal Africa (Carthage), the schools of the grammarians and rhetoricians survived for a time, and, even in those places where such schools soon disappeared, as in Gaul and in Spain, private teachers or parents maintained the tradition of classical culture until the 7th century. As in previous centuries, the culture bestowed was essentially literary and oratorical: grammar and rhetoric constituted the basis of the studies. The pupils read, reread, and commented on the classical authors and imitated them by composing certain kinds of exercises (*dictiones*) with the aim of achieving a perfect mastery of their style. In fact, however, the practice was desultory, and the results were mechanical and poor. Greek was ignored more and more, and attempts to revive Hellenic studies were limited to a dwindling number of scholars.

Christianity, meanwhile, was becoming more formally organized, and in the Latin-speaking western division of the empire, the Catholic church (as it was beginning to

be called, from the Greek *katholikos,* the "whole") had developed an administrative pattern, based upon that of the empire itself, for which learning was essential for the proper discharge of its duties. Schools began to be formed in the rudimentary cathedrals, although the main centres of learning from the 5th century to the time of Charlemagne in the 8th century were in the monasteries. The prototype of Western monasticism was the great monastery founded at Monte Cassino in 529 by Benedict of Nursia (*c.* 480–*c.* 547), probably on the model of Vivarium, the scholarly monastery established by Cassiodorus. The rule developed by Benedict to guide monastic life stimulated many other foundations, and one result was the rapid spread of Benedictine monasteries and the establishment of an order. The Benedictine monasteries became the chief centres of learning and the source of the many literate scribes needed for the civil administration.

Monastic and episcopal schools

The monastic schools, however, are no more significant in the history of education than the schools founded by bishops, usually in connection with a cathedral. These episcopal schools are sometimes looked upon as successors of the grammar schools of the Roman Empire. First specializing in the development of the clergy, they later admitted young lay people when the small Roman schools had disappeared. At the same time there were bishops who organized a kind of boarding school where the aspiring clergyman, living in a community, participated in duties of a monastic character and learned his clerical trade.

The influence of monasticism affected the content of instruction and the method of presenting it. Children were to be dutiful, as the Celtic and English monks Columban and Bede were to remark: "A child does not remain angry, he is not spiteful, does not contradict the professors, but receives with confidence what is taught him." In the case of the adolescent destined for a religious profession, the monastic lawgiver was severe. The teacher must know and teach the doctrine, reprimand the undisciplined, and adapt his method to the different temperaments of the young monks. The education of young girls destined for monastic life was similar: the mistress of the novices recommended prayer, manual work, and study.

Education of the laity

Between the 5th and 8th centuries the principles of education of the laity likewise evolved. The treatises on education, later called the "mirrors," pointed to the importance of the four moral virtues—prudence, courage, justice, and temperance. The *Institutionum disciplinae* of an anonymous Visigoth pedagogue expressed the desire that all young men "quench their thirst at the quadruple fountain of the virtues." In the 7th and 8th centuries the moral concepts of antiquity completely surrendered to religious principles. The Christian Bible was more and more considered as the only source of moral life, as the mirror in which men must learn to see themselves. A bishop addressing himself to a son of the Frankish king Dagobert (died 639) drew his examples from the books of the Old Testament. The mother of Didier of Cahors addressed to her son letters of edification on the fear of God, on the horror of vice, and on penitence.

The Christian education of children who were not aristocrats or future clergymen or monks was irregular. Whereas in antiquity catechetical instruction was organized especially for the adult laity, after the 5th century more and more children and then infants received baptism, and, once baptized, a child was not required to receive any particular religious education. His parents and godparents assisted him in learning the minimum, if anything at all. Only by attending church services and listening to sermons did the child acquire his religious culture.

The Irish and English revivals. During the 5th and 6th centuries there was a renaissance of learning in the remote land of Ireland, introduced there initially by the patron saints of Ireland—Patrick, Bridget, and Columba—who established schools at Armagh, Kildare, and Iona. They were followed by a number of other native scholars, who also founded colleges—the most famous and greatest university being the one at Clonmacnois, on the Shannon River near Athlone. To these and lesser schools flocked Anglo-Saxons, Gauls, Scots, and Teutons from Britain and the Continent. From about AD 600 to 850, Ireland itself sent scholars to the Continent to teach, found monasteries, and establish schools.

Although the very earliest Irish scholars may have aimed primarily at propagating the Christian faith, their successors soon began studying and teaching the Greek and Roman classics (but only in Latin versions), along with Christian theology. Eventually there were additions of mathematics, nature study, rhetoric, poetry, grammar, and astronomy, all studied, it seems, very largely through the medium of the Irish language.

England was next to experience the reawakening, and, though there were notable schools at such places as Canterbury and Winchester, it was in Northumbria that the schools flourished most. At the monasteries of Jarrow and Wearmouth and at the Cathedral School of York, some of the greatest of early medieval writers and schoolmasters appeared, including the Venerable Bede and Alcuin. The latter went to France in 780 to become master of Charlemagne's palace school.

THE CAROLINGIAN RENAISSANCE AND ITS AFTERMATH

The cultural revival under Charlemagne and his successors. Charlemagne (742/743–814) has been represented as the sponsor or even creator of medieval education, and the Carolingian renaissance has been represented as the renewal of Western culture. This renaissance, however, built on earlier episcopal and monastic developments; and, although Charlemagne did help to ensure the survival of scholarly traditions in a relatively bleak and rude age, there was nothing like the general advance in education that occurred later with the cultural awakening of the 11th and 12th centuries.

Educational reforms of Charlemagne

Learning, nonetheless, had no more ardent friend than Charlemagne, who came to the Frankish throne in 768 distressed to find extremely poor standards of Latin prevailing. He thus ordered that the clergy be educated severely, whether by persuasion or under compulsion. He recalled that, in order to interpret the Holy Scriptures, one must have a command of correct language and a fluent knowledge of Latin; he later commanded, "in each bishopric and in each monastery let the psalms, the notes, the chant, calculation and grammar be taught and carefully corrected books be available" (capitulary of AD 789). His promotion of ecclesiastical and educational reform bore fruit in a generation of churchmen whose morals and whose education were of a higher standard than before.

The possibility then arose of providing, for the brighter young clerics and perhaps also for a few laymen, a more advanced religious and academic training. It was perhaps to meet this modest need that a school grew up within the precincts of the emperor's palace at Aachen. In order to develop and staff other centres of culture and learning, Charlemagne imported considerable foreign talent. During the 8th century England had been the scene of some intellectual activity; thus, Alcuin, who had been the master of the school at York, and other English scholars were brought over to transplant to the Continent the studies and disciplines of the Anglo-Saxon schools. From Moorish Spain came Christian refugees who also contributed to this intellectual revival; disputations with the Muslims had forced them to develop a dialectic skill in which they now instructed Charlemagne's subjects. From Italy came grammarians and chroniclers, men such as Paul the Deacon; the more formalistic classical traditions in which they had been bred supplied the framework to discipline the effervescent brilliance of the Anglo-Saxons. Irish scholars also arrived. Thanks to these foreigners, who represented the areas where classical and Christian culture had been maintained in the 6th and 8th centuries, the court became a kind of "academy," to use Alcuin's term. There the emperor, his heirs, and his friends discussed various subjects—the existence or nonexistence of the underworld and of nothingness, the eclipse of the sun, the relationship of Father, Son, and Holy Spirit, and so on. Recognizing the importance of manuscripts in the cultural revival, Charlemagne formed a library (the catalog of which is still extant), had texts and books copied and recopied, and bade every school to maintain a scriptorium. Alcuin developed a school of calligraphy at Tours, and its new

script spread rapidly throughout the empire; this Carolingian minuscule was more legible and less wasteful of space than the uncial scripts hitherto employed.

Outside the court at Aachen were to be found here and there a few seats of culture, but not many. The archbishop of Lyon reorganized the schools of readers and choir leaders; Alcuin in Saint-Martin-de-Tours and Angilbert in Saint-Riquier organized monastic schools with relatively well-stocked libraries. It was necessary to wait for the second generation or even the third to witness the greatest brilliance of the Carolingian renewal. Under Charlemagne's son Louis the Pious and especially under his grandsons, the monastic schools reached their apogee in France north of the Loire, in Germany, and in Italy. The most famous were at Saint-Gall, Reichenau, Fulda, Bobbio, Saint-Denis, Saint-Martin-de-Tours, and Ferrières. Unfortunately, the breakup of the Carolingian empire, following local rebellions and the Viking invasions, ended the progress of the Carolingian renaissance.

Educational accomplishments of Alfred the Great

Influences of the Carolingian renaissance abroad. In England, at least in the kingdom of Wessex, King Alfred the Great stands out as another royal patron of learning, one who wanted to imitate the creativity of Charlemagne. When he came to the throne in 871, cultural standards had fallen to a low level, partly because of the turmoil of the Danish invasions. He was grieved to find so few who could understand Latin church services or translate a letter from Latin into English. To accomplish an improvement, he called upon monks from the Continent, particularly those of Saint-Bertin. Moreover, he attracted to his court certain English clergy and young sons of nobles. Since the latter did not know Latin, he had translated into Wessex English some works of Pope Gregory the Great, Boethius, the theologian and historian Paulus Orosius, Venerable Bede, St. Augustine, and others. He himself translated Boethius' *Consolation of Philosophy,* Gregory the Great's *Pastoral Care,* and Bede's *Ecclesiastical History of the English People.* This promotion of learning was continued by Alfred's successors and spread elsewhere in England; and in the reformed monasteries at Canterbury, York, and Winchester, the young monks renewed the study of religious and secular sciences. Among the master scholars of the late 10th century was the Benedictine monk Aelfric, perhaps the greatest prose writer of Anglo-Saxon times. In order to facilitate the learning of Latin for young monks, Aelfric composed a grammar, glossary, and colloquy, containing a Latin grammar described in Anglo-Saxon, a glossary in which master and pupil could find a methodically classified Latin vocabulary (names of birds, fish, plants, and so forth), and a manual of conversation, inspired by the bilingual manuals of antiquity.

Among the other Saxons, those of the Continent who presided over the destinies of Germany, there were also significant gatherings of masters and students at selected monasteries, such as Corvey and Gandersheim. In any case, wherever teaching became important in the 10th century, it concentrated largely on grammar and the works of the classical authors. Thus when Gerbert of Aurillac, after a course of instruction in Catalonia, came to teach dialectic and the arts of the quadrivium (geometry, arithmetic, harmonics, and astronomy) at Reims, he aroused astonishment and admiration. His renown helped in his later election as Pope Sylvester II. The first half of the 11th century contained the first glimmerings of a rediscovered dialectic. A new stage in the history of teaching was beginning.

Religious and military emphases of general education

Education of the laity in the 9th and 10th centuries. The clergy who dominated society thought it necessary to give laymen some directives about life comparable to those offered in monastic rules and thus issued what were called *miroirs* ("mirrors"), setting forth the duties of a good sovereign and exalting the Christian struggle. Already the image of the courtly and Christian knight was beginning to take shape. It was not a question of governing a state well but, rather, of governing oneself. The layman must struggle against vice and practice virtue; he must emphasize his religious heritage. Alcuin became indignant when he heard it said that the reading of the Gospel was the duty of the clergy and not that of the layman. Huoda, wife of Bernard, duke of Septimania, addressed a manual to her 16-year-old son, stressing the reading and praying that a young man should do. In the libraries of the laity, the volumes of the Old and New Testaments took first place, along with prayer books, a kind of breviary designed for day-to-day use.

If a minority of aristocrats could receive a suitable moral and religious education, the masses remained illiterate and preferred a military apprenticeship to study. "He who has remained in school up to twelve years without mounting a horse is no longer good for anything but the priesthood," wrote a German poet. Writers of hagiographic texts were fond of contrasting the mother of the future saint, anxious to give education to her son, and the father, who wanted to harden his son at an early age to the chase or to war. The Carolingian tradition, however, was not totally forgotten by princes and others in high places. In Germany, Otto I and his successors, who wished to re-create the Carolingian empire, encouraged studies at the court: Wipo, the preceptor of Henry III, set out a program of education for the laity in his *Proverbia.* Rediscovering the ancient moralists, chiefly Cicero and Seneca, he praised moderation as opposed to warlike brutality or even the ascetic strength of the monks. The same tendency is found in other writings.

THE MEDIEVAL RENAISSANCE

The era that has been called the "renaissance of the 12th century" corresponds to a rediscovery of studies originating in the 11th century in a West in the process of transformation. The church cast off the tutelage of lay power, and there was general acceptance of the authority of the church in matters of belief, conduct, and education; the papacy took over the direction of Christianity and organized the Crusades to the East; the monarchies regrouped the political and economic forces of feudal society; the cities were reanimated and were organized into communes; the merchants traced out the great European trade routes and, before long, the Mediterranean ones. Soon contact with the East, by trade and in the Crusades, and with the highly cultivated Moors in Spain further stimulated intellectual life. Arabic renderings of some of the works of Aristotle, together with commentaries, were translated into Latin, exercising a profound influence on the trend of culture. It was inevitable that the world of education would take on a new appearance.

Decline of monastic studies

Changes in the schools and philosophies. *Monastic schools.* In the first place, the monastic reformers made the decision to close their schools to those who did not intend to enter upon a cloistered life. According to their idea of solitude and sanctity, recalling the words of St. Jerome, "the monk was not made to teach but to mortify himself." Divine works were to be the only object of study and meditation, and Pierre de Celle asserted that "divine science ought to mould rather than question, to nourish conscience rather than knowledge."

The scholarly monks completed their studies before being admitted to the monastery—the age of entrance in Benedictine houses, for instance, being fixed at 15 years at Cîteaux and 20 years at Cluny. If there were admitted a few oblates (who were laymen living in monasteries under modified rules), they were given an ascetic and moral education and were taught to read the Holy Writ and, what was still more desirable, to "relish" it. In the Carthusian monastery the four steps of required spiritual exercise were reading, meditation, prayer, and contemplation. Thus, there existed a monastic culture, but there were no truly monastic studies such as those that had existed in the 9th and 10th centuries. The rich libraries of the monasteries served only a few scholarly abbots, while the monks searched for God through prayer and asceticism.

Urban schools. In the cities, on the contrary, the schools offered to all the clergy who so desired the means of satisfying their intellectual appetite. More and more of them attended these schools, for the studies were a good means of social advancement or material profit. The development of royal and municipal administrations offered the clergy new occupations. Hence the success of the schools for notaries and the schools of law and rhetoric.

These schools were organized under the protection of the collegiate churches and the cathedrals. The schools for secular subjects were directed by an archdeacon, chancellor, cantor, or cleric who had received the title of *scholasticus, caput scholae,* or *magister scholarum* and who was assisted by one or more auxiliary masters. The success of the urban schools was such that it was necessary, in the middle of the 12th century, to define the teaching function. Only those could teach who were provided with the *licencia docendi* conferred by the bishop or, more often, by the *scholasticus.* Those who were licensed taught within the limits of the city or the diocese, whose clerical leaders supervised this monopoly and intervened if a cleric set himself up as master without having the right. The popes were sufficiently concerned about licensing that the Lateran Council of 1179 gave this institution universal application.

New curricula and philosophies. The pupils who attended these urban schools learned in them their future occupation as clerics; they learned Latin, learned to sing the various offices, and studied Holy Writ. The more gifted ones extended their studies further and applied for admission to the liberal arts (the trivium, made up of grammar, rhetoric, and logic; and the quadrivium, including geometry, arithmetic, harmonics, and astronomy) and, upon completion of the liberal arts, to philosophy. Philosophy had four branches: theoretical, practical, logical, and mechanical. The theoretical was divided into theology, physics, and mathematics; the practical consisted of morals or ethics (personal, economic, political). The logical, which concerned discourse, consisted of the three arts of the trivium. Finally, the mechanical included the work of processing wool, of navigation, of agriculture, of medicine, and so on. This was an ambitious humanistic program. In fact, the students became specialized in the study of one art or another according to their tastes or the presence of a renowned master, such as Guillaume de Champeaux at Paris and St. Victor for rhetoric and theology; Peter Abelard at Paris for dialectic and theology; Bernard de Chartres for grammar; William of Conches at Chartres for grammar, ethics, and medicine; and Thierry de Chartres for rhetoric. In particular, teachers of the "literary" arts, grammar and rhetoric, always had great success in a period of enthusiasm for the ancient authors. It may be noted that Bernard de Chartres organized his literary teaching in this fashion: grammatical explanations (*declinatio*), studies of authors, and each morning the correction of the exercises given the day before.

Study of the liberal arts and philosophy

The third art of the trivium, logic (or dialectics), was nevertheless a strong competitor of the other two, grammar and rhetoric. Since the 11th century, Aristotle's *Posterior Analytics,* which had been translated centuries earlier by Boethius, had developed the taste for reasoning, and, by the time that Abelard arrived in Paris around 1100, interest in dialectics was flourishing. The written words of the Scriptures and of the Fathers of the Church were to be subjected to the scrutiny of human reason; a healthy skepticism was to be the stepping-stone to knowledge, aided by an understanding of critical logic. While dialectic reigned in Paris, the masters at Chartres offered a study of the whole of the quadrivium. This interest in the sciences, which had been manifest at Chartres since the early 11th century, had been favoured by the stimulus of Greco-Arabic translations. The works of Euclid, Ptolemy, Hippocrates, Galen, and other Hellenic and Hellenistic scholars, as preserved in the Arabic manuscripts, were translated in southern Italy, Sicily, and Spain and were gradually transmitted northward. The scientific revival allowed the Chartrians to Christianize Greek cosmology, to explain Genesis according to physics, and to rediscover nature. Another revival was that of law. The conflicts in the second half of the 12th century between the church and the lay powers encouraged on both sides a new activity in the juridical field. The princes found in the Corpus Juris Civilis, the 6th-century Roman code of the emperor Justinian, the means of legitimizing their politics, and the papacy likewise used Roman sources to promote its claims.

Thomist philosophy. In the long view, the greatest educational and philosophical influence of the age was St. Thomas Aquinas, who in the 13th century made a monumental attempt to reconcile the two great streams of the Western tradition. In his teaching at the University of Paris and in his writings—particularly the *Summa theologiae* and the *Summa contra gentiles*—Aquinas tried to synthesize reason and faith, philosophy and theology, university and monastery, activity and contemplation. In his writings, however, faith and theology ultimately took precedence over reason and philosophy because the former were presumed to give access to truths that were not available through rational inquiry. Hence, Aquinas started with assumptions based on divine revelation and went on to a philosophical explication of man and nature. The model of the educated man that emerged from this process was the Scholastic, a man whose rational intelligence had been vigorously disciplined for the pursuit of moral excellence and whose highest happiness was found in contemplation of the Christian God.

The Scholastic model

The Scholastic model greatly affected the development of Western education, especially in fostering the notion of intellectual discipline. Aquinas' theological-philosophical doctrine was a powerful intellectual force throughout the West, being officially adopted by the Dominican order (of which Aquinas was a member) in the 13th century and by the Jesuits in the 17th century. Known as Thomism, this doctrine came to constitute the basis of official Roman Catholic theology from 1879. Although Aquinas made an important place in his hierarchy of values for the practical uses of reason, later Thomists were often more exclusively intellectual in their educational emphasis.

The development of the universities. The Middle Ages were thus beset by a multiplicity of ideas, both homegrown and imported from abroad. The multiplicity of students and masters, their rivalries, and the conflicts in which they opposed the religious and civil authorities obliged the world of education to reorganize. To understand the reorganization, one must review the various stages of development in the coming together of students and masters. The first stage, already alluded to, occurred when the bishop or some other authority began to accord to other masters permission to open schools other than the episcopal school in the neighbourhood of his church. A further stage was reached when a license to teach, the *jus ubique docendi*—granted only after a formal examination—empowered a master to carry on his vocation at any similar centre. A further development came when it began to be recognized that, without a license from pope, emperor, or king, no school could be formed possessing the right of conferring degrees, which originally meant nothing more than licenses to teach.

Students and teachers, as *clerici* ("clerks," or members of the clergy), enjoyed certain privileges and immunities, but, as the numbers traveling to renowned schools increased, they needed additional protection. In 1158 Emperor Frederick I Barbarossa of the Holy Roman Empire granted them privileges such as protection against unjust arrest, trial before their peers, and permission to "dwell in security." These privileges were subsequently extended and included protection against extortion in financial dealings and the *cessatio,* or the right to strike, discontinue lectures, and even to secede to protest against grievances or interference with established rights.

In the north of Europe licenses to teach were granted by the chancellor, *scholasticus,* or some other officer of a cathedral church; in the south it is probable that the guilds of masters (when these came to be formed) were at first free to grant their own licenses, without any ecclesiastical or other supervision. Gradually, however, toward the end of the 12th century, a few great schools, from the excellence of their teaching, came to assume more than local importance. In practice, a doctor of Paris or Bologna would be allowed to teach anywhere; and those great schools began to be known as studia generalia; that is, places resorted to by scholars from all parts. Eventually the term came to have a more definite and technical significance. The emperor Frederick II in 1225 set the example of attempting to confer upon his new school at Naples, by an authoritative bull, the prestige that the earlier *studia* had acquired by reputation and general consent. Pope Gregory IX did the

The studia generalia and the *universitas*

same for Toulouse in 1229, and he added to its original privileges in 1233 a bull by which anyone who had been admitted to the doctorate or mastership in that university should have the right to teach anywhere without further examination. Other studia generalia were subsequently founded by papal or imperial bulls, and in 1292 even the oldest universities, Paris and Bologna, found it desirable to obtain similar bulls from Pope Nicholas IV. From this time the notion began to prevail that the essence of the studium generale was the privilege of conferring a universally valid teaching license and that no new *studium* could acquire that position without a papal or imperial bull. There were, however, a few studia generalia (such as Oxford) the position of which was too well established to be questioned, even though they had never obtained such a bull; these were held to be studia generalia by repute. A few Spanish universities founded by royal charter were held to be studia generalia for the kingdom.

The word *universitas* originally applied only to the scholastic guild (or guilds)—that is, the corporation of students and masters—within the *studium,* and it was always modified, as *universitas magistrorum,* or *universitas scholarium,* or *universitas magistrorum et scholarium.* In the course of time, however, probably toward the latter part of the 14th century, the term began to be used by itself, with the exclusive meaning of a self-regulating community of teachers and scholars whose corporate existence had been recognized and sanctioned by civil or ecclesiastical authority.

The Italian universities. The earliest *studia* arose out of efforts to provide instruction beyond the range of the cathedral and monastic schools for the education of priests and monks. Salerno, the first great *studium,* became known as a school of medicine as early as the 9th century, and, under the teaching of Constantine the African (died 1087), its fame spread throughout Europe. In 1231 it was licensed by Frederick II as the only school of medicine in the kingdom of Naples. It remained a medical school only.

The Bologna prototype of universities

The great revival of legal studies that took place at Bologna about the year 1000 had been preceded by a corresponding activity at Pavia and Ravenna. In Bologna a certain Pepo was lecturing on parts of the Corpus Juris Civilis about the year 1076. The secular character of this new study and its close connection with the claims and prerogatives of the Western emperor aroused papal suspicion, and for a time Bologna and its students were regarded by the church with distrust. The students found their first real protector in the emperor Frederick I Barbarossa. The immunities and privileges he conferred eventually extended to all the other universities of Italy.

The first university of Bologna was not constituted until the close of the 11th century—the "universities" there being student guilds, formed to obtain by combination that protection and those rights that they could not claim as citizens. As the number of students increased, the number of *universitates,* or societies of scholars, increased, each representing the national origin of its members (France, England, Provence, Spain, Italy). These confederations were presided over by a common head, the *rector scholarium,* and the different nations were represented by their *consiliarii,* a deliberative assembly with which the rector habitually took counsel. The practice at Bologna was adopted as other studia generalia arose.

The students at Bologna were mostly of mature years. Because civil law and canon law were, at first, the only branches of study offered, the class they attracted was often composed of lawyers already filling office in some department of the church or state—archdeacons, heads of schools, canons of cathedrals, and like functionaries. About 1200 the two faculties of medicine and philosophy were formed. The former was developed by a succession of able teachers, among whom Thaddeus Alderottus was especially eminent. The faculty of arts, down to the 14th century, scarcely attained equal eminence.

At Bologna the term college long had a different meaning from the ordinary modern one. The masters formed themselves into collegia (that is, organizations), chiefly for the conferment of degrees. Places of residence for students existed at Bologna at a very early date, but it was not until the 14th century that they possessed any organization; the humble *domus,* as it was termed, was at first designed solely for necessitous students who were not natives of Bologna; a separate house, with a fund for the maintenance of a specified number of scholars, was all that was originally contemplated.

From the 13th to the 15th century a number of universities in Italy originated from migrations of students; others were established by papal or other charters. Almost all the schools taught civil or canon law or both. Of these institutions the most important were Padua, Piacenza, Pavia, Rome, Perugia, Pisa, Florence, Siena, and Turin.

The Paris prototype of universities

The French universities. The history of the University of Paris well illustrates the fact that the universities arose in response to new needs. The schools out of which the university arose were those attached to the Cathedral of Notre-Dame de Paris on the Île de la Cité and presided over by its chancellor. Although, in the second decade of the 13th century, some masters placed themselves under the jurisdiction of the abbot of the monastery of Sainte-Geneviève on the Left Bank of the Seine, it was around the bestowal of the license by the chancellor of Notre-Dame that the university grew. It is in this license that the whole significance of the master of arts degree was contained; for admission to that degree was the receiving of the chancellor's permission to "incept"; and by "inception" was implied the master's formal entrance upon the functions of a duly licensed teacher and his recognition as such by his brethren in the profession. The stage of bachelordom had been one of apprenticeship for the mastership; and his emancipation from this state was symbolized by the placing of the magisterial cap (biretta) upon his head. The new master gave a formal inaugural lecture, and he was then welcomed into the society of his professional brethren with set speeches and took his seat in his master's chair.

Some time between 1150 and 1170 the University of Paris came formally into being. Its first written statutes were not, however, compiled until about 1208, and it was not until long after that date that it possessed a "rector." Its earliest recognition as a legal corporation belongs to about the year 1211, when a brief of Innocent III empowered it to elect a proctor to be its representative at the papal court. With papal support Paris became the great transalpine centre of orthodox theological teaching. Successive pontiffs, down to the Great Schism of 1378, cultivated friendly relations with the university and systematically discouraged the formation of theological faculties at other centres. In 1231 Gregory IX, in the bull *Parens scientiarum* ("Mother of Learning"), gave full recognition to the right of the several faculties to regulate and modify the constitution of the university. The fully developed university was divided into four faculties: three superior, those of theology, canon law, and medicine; and one inferior, that of arts, which was divided into four student confederations, or nations (French, Picard, Norman, and English), which included both professors and scholars from the respective countries. The head of each faculty was the dean; of each nation, the proctor. The rector, in the first instance head of the faculty of arts, eventually became the head of the collective university.

After the close of the Middle Ages, Paris came to be virtually reduced to a federation of colleges, though at Paris the colleges were less independent of university authority than was often the case elsewhere. Other major French universities of the Middle Ages were Montpellier, Toulouse, Orléans, Angers, Avignon, Cahors, Grenoble, Orange, and Perpignan.

The English offshoots of Paris: Oxford and Cambridge

The English universities. The University of Paris became the model for French universities north of the Loire and for those of central Europe and England; Oxford would appear to have been the earliest. Certain schools, opened early in the 12th century within the precincts of the dissolved nunnery of St. Frideswide and of Oseney Abbey, are supposed to have been the nucleus around which it grew. But the beginning may have been a migration of English students from Paris about 1167 or 1168. Immediately after 1168, allusions to Oxford as a *studium* and a studium generale begin to multiply. In the 13th century, mention first occurs of university "chests," which

were benefactions designed for the assistance of poor students. Halls, or places of licensed residence for students, also began to be established. Against periodic vicissitudes such as student dispersions and plagues, the foundation of colleges proved the most effective remedy. The earliest colleges were University College, founded in 1249, Balliol College, founded about 1263, and Merton College, founded in 1264.

The University of Cambridge, although it came into existence somewhat later than Oxford, may reasonably be held to have had its origin in the same century. In 1112 the canons of St. Giles crossed the River Cam and took up their residence in the new priory in Barnwell, and their work of instruction acquired additional importance. In 1209 a body of students migrated there from Oxford. Then about 1224 the Franciscans established themselves in the town and, somewhat less than half a century later, were followed by the Dominicans. At both the English universities, as at Paris, the mendicants and other religious orders were admitted to degrees, a privilege that, until the year 1337, was extended to them at no other university. Their interest in and influence at these three centres were consequently proportionately great.

In 1231 and 1233 royal and papal letters afford satisfactory proof that the University of Cambridge was already an organized body, with a chancellor at its head.

Although both Oxford and Cambridge were modeled on Paris, their higher faculties never developed the same distinct organization; and, while the two proctors at Cambridge originally represented north and south, the nations are scarcely to be discerned. An important step was made, however, in 1276, when an ordinance was passed requiring that everyone who claimed to be recognized as a scholar should have a fixed master within 15 days after his entry into the university. The traditional constitution of the English universities was, in its origin, an imitation of the Parisian, modified by the absence of the cathedral chancellor. But the feature that most served to give permanence and cohesion to the entire community at Cambridge was, as at Oxford, the institution of colleges. The earliest of these was Peterhouse, in 1284. All the early colleges were expressly designed for the benefit of the secular clergy.

Universities elsewhere in Europe. From the 13th to the 15th centuries, studia generalia or universities proliferated in central and northern Europe and were usually modeled on the University of Paris. Although the earliest was Prague, which existed as a *studium* in the 13th century and was chartered by Pope Clement VI in 1348, perhaps no medieval university achieved a more rapid and permanent success than Heidelberg. The University of Heidelberg, the oldest in the German realm, received its charter in 1386 from Pope Urban VI as a studium generale and contained all the recognized faculties—theology, canon law, medicine, and the arts, as well as civil law. In the subsequent 100 years, universities were founded at Cologne, Erfurt, Leipzig, Rostock, Freiburg, Tübingen, Ofen (Budapest), Basel, Uppsala, and Copenhagen.

Higher education in Spain

Spain was also an important scene of developments in higher education. Valladolid received its charter in 1346 and attained great celebrity after it obtained the rank of studium generale and a *universitas theologiae* by a decree of Pope Martin V in 1418. Salamanca was founded in 1243 by Ferdinand III of Castile with faculties of arts, medicine, and jurisprudence, to which theology was added through the efforts of Martin V. The College of St. Bartholomew, the earliest founded at Salamanca, was noted for its ancient library and valuable collection of manuscripts. Other important early Spanish and Portuguese schools were Seville, Alcalá, and Lisbon.

General characteristics of medieval universities. Generally speaking, the medieval universities were conservative. Alexander Hegius and Rudolf Agricola carried on their work as reformers at places such as Deventer, in the Netherlands, remote from university influences. A considerable amount of mental activity went on in the universities; but it was mostly of the kind that, while giving rise to endless controversy, turned upon questions in connection with which the implied postulates and the terminology employed rendered all scientific investigation hopeless. At almost every university the realists and nominalists represented two great parties occupied with an internecine struggle (see EPISTEMOLOGY).

In Italian universities such controversies were considered endless and their effects pernicious. It was resolved, accordingly, to expel logic and allow its place to be filled by rhetoric, thereby effecting that important revolution in academic studies that constituted a new era in university learning and largely helped to pave the way for the Renaissance. The professorial body in the great Italian universities attained an almost unrivaled reputation throughout Europe. For each subject of importance there were always two, and sometimes three, rival chairs. While other universities became sectarian and local, those of Italy continued to be universal, and foreigners of all nations could be found among the professors.

The material life of the students was difficult. In order to aid the poorest, some colleges founded by clerical or lay benefactors offered board and lodging to a number of foundationers. Courses, too, could occasionally be difficult. The courses in theology were particularly long—eight years at the minimum (one could not be a teacher of theology in Paris before the age of 35). Many students preferred the more rapid and more lucrative paths of law and medicine. Others led the life of perpetual students, of vagabond clerics, disputatious goliards, the objects of repeated but ineffectual condemnation.

The methods of teaching are particularly well known in the case of Paris. The university year was divided into two terms: from St. Remi (October 1) to Lent and from Easter to St. Pierre (June 29). The courses consisted of lectures (*collatio*) but more often of explications of texts (*lectio*). There were also discussions and question periods. Examinations were given at the end of each term. The student could receive three degrees: the *determinatio,* or baccalaureate, gave him the right to teach under the supervision of a master; the *licencia docendi* was literally the "license to teach" and could be obtained at 21 years of age; then there was the doctorate, which marked his entrance into mastership and which involved a public examination.

Lay education and the lower schools. The founding of universities was naturally accompanied by a corresponding increase in schools of various kinds. In most parts of western Europe, there were soon grammar schools of some type available for boys. Not only were there grammar schools at cathedrals and collegiate churches, but many others were founded in connection with chantries and craft and merchant guilds and a few in connection with hospitals. It has been estimated, for example, that, toward the close of the Middle Ages, there were in England and Wales, for a population of about 2.5 million, approximately 400 grammar schools, although the number of their enrollments was generally quite small.

Early grammar schools

In fulfillment of its responsibility for education, the church from the 11th century onward made the establishment of an effective education system a central feature of ecclesiastical policy. During the papacy of Gregory VII (1073–85), all bishops had been asked to see that the art of grammar was taught in their churches, and a Lateran Council in 1215 decreed that grammar-school masters should be appointed not only in the cathedral church but also in others that could afford it. Solicitude at the centre for the advancement of education did not, however, result in centralized administration. It was the duty of bishops to carry out approved policy, but it was left to them to administer it, and they in turn allowed schools a large measure of autonomy. Such freedom as medieval schools enjoyed was, however, always subject to the absolute authority of the church, and the right to teach, as earlier noted, was restricted to those who held a bishop's license. This device was used to ensure that all teachers were loyal to the doctrines of the church.

Knowledge of the teaching provided in the grammar schools at this period is too slight to justify an attempt at a description. No doubt the curriculum varied, but religion was all-important, with Latin as a written and spoken language the other major element in the timetable. There might have been instruction in reading and writing in the vernacular, but, in addition to the grammar schools,

there were writing and song schools and other schools of an elementary type. Elementary teaching was given in many churches and priests' houses, and children who did not receive formal scholastic instruction were given oral teaching by parish priests in the doctrines and duties of the faith. The evidence of accounts, bills, inventories, and the like suggests that there was some careful teaching of writing and of an arithmetic that covered the practical calculations required in ordinary life. Literacy, however, was limited by the lack of printed materials; until the 15th century (when typesetting developed) books were laboriously cut page by page on blocks (hence they were known as block books) and consequently were rare and expensive. From the mid-15th century on, literacy increased as typeset books became more widely available.

Educational provision for girls in medieval society was much more restricted. Wealthy families made some provision in the home, but the emphasis was primarily on piety and secondarily on skills of household management, along with artistic "accomplishments." Neither girls nor boys of the lowest social ranks—peasants or unskilled urban dwellers—were likely to be literate. Nor were girls of the artisan classes until the 16th century, when female teaching congregations such as the Ursulines founded by Angela Merici began to appear. There were, however, provisions for boys of the artisan class to receive sufficient vernacular schooling to enable them to be apprenticed to various trades under the auspices of the guilds.

Training for feudalism

There was an entirely different training for boys of high rank, and this created a cultural cleavage. Instead of attending the grammar school and proceeding to a university, these boys served as pages and then as squires in the halls and castles of the nobility, there receiving prolonged instruction in chivalry. The training was designed to fit the noble youth to become a worthy knight, a just and prudent master, and a sensible manager of an estate. Much of this knowledge was gained from daily experience in the household, but, in addition, the page received direct instruction in reading and writing, courtly pastimes such as chess and playing the lute, singing and making verses, the rules and usages of courtesy, and the knightly conception of duty. As a squire he practiced more assiduously the knightly exercises of war and peace and acquired useful experience in leadership by managing large and small bodies of men. But this was a type of education that could flourish only in a feudal society; and, though some of its ideals survived, it was outmoded when feudalism was undermined by the growth of national feeling.

(P.R./J.Bo.)

Education in Asian civilizations: c. 700 to the eve of Western influence

INDIA

During its medieval period, India was ruled by dynasties of Muslim culture and religion. Muslims from Arabia first appeared in the country in the 8th century, but the foundation of their rule was laid much later by Muḥammad Ghūri, who established his power at Delhi in 1192. The original Muslim rule was replaced successively by that of the Muslim Pashtuns and Mughals.

The foundations of Muslim education. Muslim educational institutions were of two types—a *maktab,* or elementary school, and a madrasah, or institution of higher learning. The content of education imparted in these schools was not the same throughout the country. It was, however, necessary for every Muslim boy at least to attend a *maktab* and to learn the necessary portions of the Qur'ān required for daily prayers. The curriculum in the madrasah comprised Ḥadith (the study of Muslim traditions), jurisprudence, literature, logic and philosophy, and prosody. Later on, the scope of the curriculum was widened, and such subjects as history, economics, mathematics, astronomy, and even medicine and agriculture were added. Generally, all the subjects were not taught in every institution. Selected madrasahs imparted postgraduate instruction, and a number of towns—Āgra, Badaun, Bidar, Gulbarga, Delhi, Jaunpur, and a few others—developed into university centres to which students flocked for study under renowned scholars. The sultans and amirs of Delhi and the Muslim rulers and nobles in the provinces also extended patronage to Persian scholars who came from other parts of Asia under the pressure of Mongol inroads. Delhi vied with Baghdad and Cōrdoba as an important centre of Islāmic culture. Indian languages also received some attention. The Muslim rulers of Bengal, for example, engaged scholars to translate the Hindu classics, the *Rāmāyaṇa* and the *Mahābhārata,* into Bengali.

Developments under the Pathans

Under the Pathan Lodis, a dynasty of Afghan foreigners (1451–1526), the education of the Hindus was not only neglected but was often adversely affected in newly conquered territories. The rulers generally tolerated Sanskrit and vernacular schools already in existence but did not help the existing ones with money or build new ones. At early stages, the *maktab*s and madrasahs were attended by Muslims only. Later, when Hindus were allowed into high administrative positions, Hindu children began to receive Persian education in Muslim schools.

The Mughal period. The credit for organizing education on a systematic basis goes to Akbar (lived 1542–1605), a contemporary of Queen Elizabeth I of England and undoubtedly the greatest of Mughal emperors. He treated all his subjects alike and opened a large number of schools and colleges for Muslims as well as for Hindus throughout his empire. He also introduced a few curricular changes, based on students' individual needs and the practical necessities of life. The scope of the curriculum was so widened as to enable every student to receive education according to his religion and views of life. The adoption of Persian as the court language gave further encouragement to the Hindus and the Muslims to study Persian.

Akbar's policy was continued by his successors Jahāngīr and Shāh Jahān. But his great-grandson Aurangzeb (1618–1707) changed his policy with regard to the education of the Hindus. In April 1669, for instance, he ordered the provincial governors to destroy Hindu schools and temples within their jurisdiction; and, at the same time, he supported Muslim education with a certain religious fanaticism. After his death, the glory of the Mughal empire began gradually to vanish, and the whole country was overrun by warlords.

During the Mughal period, girls received their education at home or in the house of some teacher living in close proximity. There were special arrangements for the education of the ladies of the royal household, and some of the princesses were distinguished scholars. Vocational education was imparted through a system of apprenticeship either in the house of *ustād*s (teachers) or in *kārkhānah*s (manufacturing centres).

Muslim rulers of India were also great patrons of literature and gave considerable impetus to its development. Akbar ordered various Hindu classics and histories translated into Persian. In addition, a number of Greek and Arabic works were translated into Persian. Literary activities did not entirely cease even in the troubled days of later rulers. Men of letters were patronized by such emperors as Bahādur Shāh and Muḥammad Shāh and by various regional officials and landlords.

Educational accomplishments of the Muslim period

Such is the history of Muslim education in India. It resembles ancient Indian education to a great extent: instruction was free; the relation between the teachers and the taught was cordial; there were great centres of learning; the monitorial system was used; and people were preoccupied with theology and the conduct of life. There were, however, several distinctive features of Muslim education. First, education was democratized. As in mosques, so in a *maktab* or madrasah, all were equal, and the principle was established that the poor should also be educated. Second, Muslim rule influenced the system of elementary education of the Hindus, which had to accommodate itself to changed circumstances by adopting a new method of teaching and by using textbooks full of Persian terms and references to Muslim usages. Third, the Muslim period brought in many cultural influences from abroad. The courses of studies were both widened and brought under a humanistic influence. Finally, Muslim rule produced a cross-cultural influence in the country through the establishment of an educational system in which Hindus and

Muslims could study side by side and in which there would be compulsory education in Persian, cultivation of Sanskrit and Hindi, and translation of great classics of literature into different languages. Ultimately, it led to the development of a common medium of expression, Urdu.

Education in the Muslim era was not a concerted and planned activity but a voluntary and spontaneous growth. There was no separate administration of education, and state aid was sporadic and unsteady. Education was supported by charitable endowments and by lavish provision for the students in a madrasah or in a monastery.

The Muslim system, however, proved ultimately harmful. In the early stages genuine love of learning attracted students to the cultural centres, but later on "the bees that flocked there were preeminently drones." The whole system became stagnant and stereotyped as soon as cultural communication was cut off from the outside world because of political disturbances and internecine wars. The Indian teachers were reduced to dependence on their own resources, and a hardening tradition that became increasingly unreceptive to new ideas reduced the whole process to mere routine. (S.N.M.)

CHINA

The T'ang dynasty (AD 618–907). The T'ang was one of China's greatest dynasties, marked by military power, political stability, economic prosperity, and advance in art, literature, and education. It was an age in which Buddhist scholarship won recognition and respect for its originality and high intellectual quality and in which China superseded India as the land from which Buddhism was to spread to other countries in East Asia.

The T'ang was known for its literature and art and has been called the golden age of Chinese poetry. There were thousands of poets of note who left a cultural legacy unsurpassed in subsequent periods and even in other lands. Prose writers also flourished, as did artists whose paintings reflected the influences of Buddhism and Taoism.

One of the greatest gifts of China to the world was the invention of printing. Block printing was invented in the 8th century and movable type in the 11th century. The first book printed from blocks was a Buddhist sutra, or set of precepts, in 868. Printing met the demand created by the increase in the output of literature and by the regularized civil service examination system. It also met the popular demand for Buddhist and Taoist prayers and charms. One historian (Kenneth Scott Latourette) noted that "as late as the close of the eighteenth century the [Chinese] Empire possibly contained more printed books than all the rest of the world put together."

Education in the T'ang dynasty was under the dominant influence of Confucianism, notwithstanding the fact that Buddhism and Taoism both received imperial favours. A national academic examination system was firmly established, and officials were selected on the basis of civil service examinations. But Confucianism did not dominate to the extent of excluding other schools of thought and scholarship. Renowned scholars were known to spurn public office because they were not satisfied with a narrow interpretation of Confucianism. Artists and poets were, in general, rebellious against traditional Confucianism.

An emperor in the 5th century ordered the establishment of a "School of Occult Studies" along with the more commonly accepted schools of Confucian learning. It was devoted to the study of Buddhism and Taoism and occult subjects that transcended the practical affairs of government and society. Such schools were often carried on by the private effort of scholars who served as tutors for interested followers.

School structure in the T'ang era

The schools of T'ang were well organized and systematized. There were schools under the central government, others under local management, and private schools of different kinds. Public schools were maintained in each prefecture, district, town, and village. In the capital were "colleges" of mathematics, law, and calligraphy, as well as those for classical study. There was also a medical school.

Semiprivate schools formed by famous scholars gave lectures and tutelage to students numbering in the hundreds. Students from Korea and Japan came to study in China and took back the lunar calendar and the Buddhist sects, as well as the examination system and the Confucian theories of government and social life. Chinese culture also penetrated Indochina.

The examination system was at this time given the form that remained essentially unchanged until the 20th century. Examinations were held on different levels, and for each a corresponding academic degree was specified. Interestingly, there was provision for three degrees, not unlike the bachelor's, master's, and doctor's degrees of modern times. The first degree was the *hsiu ts'ai* ("cultivated talent"), the second the *ming ching* ("understanding the classics"), and the third the *chin-shih* ("advanced scholar"). The name of the second degree was in later periods changed to *chü jen* ("recommended man"). An academy of scholars later known as the Hanlin Academy was established for select scholars whom the emperor could call upon for advice and expert opinion on various subjects. Membership in this institution became the highest honour that could be conferred upon those who passed the *chin-shih* degree with distinction. To be appointed a Hanlin scholar was to be recognized as one of the top scholars of the land. Among the services that they rendered were the administration and supervision of examinations and the explanation of difficult texts in literature, classics, and philosophy.

Examinations were given for students of medicine and for military degrees. The study of medicine included acupuncture and massage, as well as the treatment of general diseases of the body and those of eye, ear, throat, and teeth.

The Sung (960–1279). The Sung was another dynasty of cultural brilliance. Landscape painting approached perfection, and cultural achievement was stimulated by the invention of movable type (first made of earthenware, then of wood and metal). This advance from the older method of block printing led to the multiplication of books; the printing of a complete set of the classics was a boon to literary studies in schools.

The rulers of Sung were receptive to new ideas and innovative policies. The outstanding innovator of the dynasty was Wang An-shih, prime minister from 1068 to 1076. He introduced a comprehensive program of reform that included important changes in education; more emphasis was subsequently placed on the study of current problems and political economy.

Educational controversy in the Sung era

Wang's reforms met with opposition from conservatives. The controversy was only a phase of a deeper and more far-reaching intellectual debate that made the philosophical contributions of the Sung scholars as significant as those of the Hundred Schools in the Chou dynasty over a millennium earlier. Confucianism and the dominant mode of Chinese thinking had been subject to the challenge of ideas from legalism, Taoism, and Buddhism, and, despite the resistance of conservatives, the traditional views had to be modified. Outstanding Confucian scholars of conservative bent argued vigorously with aggressive proponents of new concepts of man, of knowledge, and of the universe. The result was Neo-Confucianism, or what some prefer to call rational philosophy. The most eminent Neo-Confucianist was Chu Hsi, a Confucian scholar who had studied Taoism and Buddhism. His genius lay in his ability to synthesize ideas from a fresh point of view. Sung scholars distinguished themselves in other fields, too. Ssu-ma Kuang's *Tzu-chih t'ung-chien* ("Comprehensive Mirror for Aid in Government") was a history of China from the 5th century BC to the 10th century AD. The result of 20 years of painstaking research, it consisted of 1,000 chapters prepared under imperial direction. A volume on architecture was produced that is still used today as a basic reference work, and a treatise on botany contained the most ancient record of varieties of citrus fruits then known in China. No less worthy of mention is an encyclopaedia titled *T'ai-ping yü lan.*

The general pattern of the school system remained essentially the same, with provision for lower schools, higher schools, and technical schools, but there was a broadening of the curriculum. A noteworthy development was the rise of a semiprivate institution known as the *shu-yüan,* or academy. With financial support coming from both state grants and private contributions, these academies were

Academies

managed by noted scholars of the day and attracted many students and lecturers. Often located in mountain retreats or in the woods, they symbolized the influence of Taoism and Buddhism and a desire to pursue quiet study far away from possible government interference.

The Mongol period (1206–1368). The Mongols were ferocious fighters but inept administrators. Distrustful of the Chinese, they enlisted the services of many nationalities and employed non-Chinese aliens. To facilitate the employment of these aliens, the civil service examinations were suspended for a number of years. Later, when a modified form of examinations was in effect, there were special examinations for Mongol candidates to make sure of their admission into high offices.

The Mongols despised the Chinese and placed many limitations on them. Consequently, an aftermath of Mongol rule was a strong antiforeign reaction on the part of the Chinese, accompanied by an overanxious desire to preserve the Chinese heritage.

Despite the setback in Chinese culture under Mongol rule, the period was not devoid of positive cultural development. The increase in foreign contacts as a result of travel to and from China brought new ideas and new knowledge of other lands and other peoples. Mathematics and medicine were further influenced by new ideas from abroad. The classics were translated into the Mongol language, and the Mongol language was taught in schools.

Private schools and the academies of the Sung dynasty became more popular. As a result of a decrease in opportunities for government appointment, scholars withdrew into the provinces for study and tutoring. Relieved of the pressure of preparing for the examinations, they applied their talents to the less formal but more popular arts and literary forms, including the drama and the novel. Instead of the classical form, they used the vernacular, or the spoken, language. The significance of this development was not evident until the 20th century, when a "literary revolution" popularized the vernacular tongue.

The Ming period (1368–1644). The Ming dynasty restored Chinese rule. Ming was famous for its ceramics and architecture. There were excellent painters, too, but they were at best the disciples of the T'ang and Sung masters. The outstanding intellectual contribution of the period was the novel, whose development was spurred by increases in literacy and in the demand for reading materials. Ming novels are today recognized as masterpieces of popular vernacular literature. Also of note was the compilation of *Pen-ts'ao kang-mu* ("Great Pharmacopoeia"), a valuable volume on herbs and medicine that was the fruit of 26 years of labour.

The *Yung-lo* encyclopaedia

Of considerable scholarly and educational importance was the *Yung-lo ta-tien* encyclopaedia, which marked a high point in the Chinese encyclopaedic movement. It was a gigantic work resulting from the painstaking efforts of 2,000 scholars over a period of five years. It ran into more than 11,000 volumes, too costly to print, and only two extra copies were made.

The examination system remained basically the same. In the early period of the dynasty, the schools were systematized and regularized. In the latter part of the dynasty, however, the increasing importance of the examination system relegated the schools to a secondary position. The decline of the state-supported schools stimulated the further growth of private education.

The Manchu period (1644–1911/12). Except for two capable emperors, who ruled for a span of 135 years at the beginning, the Manchu dynasty was weak and undistinguished. Under Emperors K'ang-hsi and Ch'ien-lung, learning flourished, but there was little originality. The alien Manchu rulers concentrated on the preservation of what seemed best for stability and the maintenance of the status quo. They wanted new editions of classical and literary works, not creative contributions to scholarship.

Distrust of the Chinese by the Manchus and a feeling of insecurity caused the conquerors to erect barriers between themselves and the Chinese. The discriminatory policy was expressed in the administration of the examinations. To assure the appointment of Manchus to government posts, equal quotas were set aside for the Manchus and the Chinese, although the former constituted only about 3 percent of the population. The Chinese thus faced the keenest competition in the examinations, and those who passed tended to be brilliant intellects, whereas the Manchus could be assured of success without great effort.

Schools were encouraged and regulated during the early period of the dynasty. The public school system consisted of schools for nobles, national schools, and provincial schools. Separate schools were maintained for the Manchus, and, for their benefit, Chinese books were translated into the Manchu language. Village and charitable schools were supported by public funds, but they were neglected in later years; so that, by the end of the dynasty, private schools and tutoring had overshadowed them.

At the threshold of the modern era, China had sunk into political weakness and intellectual stagnation. The creativity and originality that had brightened previous periods of history were now absent. Examinations dominated the educational scene, and the content of the examinations was largely literary and classical. Taoism and Buddhism had lost their intellectual vigour, and Confucianism became the unchallenged model of scholarship.

Much could be said for the Chinese examination system at its best. It was instrumental in establishing an intellectual aristocracy whereby the nation could be sure of a cultural unity by entrusting government to scholars reared in a common tradition, nurtured in a common cultural heritage, and dedicated to common ideals of political and social life. It established a tradition of government by civilians and by scholars. It made the scholars the most highly esteemed people of the land. The examinations provided an open road to fame and position. Chinese society was not without classes, but there was a high degree of social mobility, and education provided the opportunity for raising one's position and status. There were no rigid prerequisites and no age limits for taking the examinations. Selection was rigorous, but the examinations were, on the whole, administered with fairness. The names of the candidates did not appear on the examination papers, and the candidates were not permitted to have any outside contacts while writing them.

Influence of the examination system

Nevertheless, the system had serious drawbacks. The content of the examinations became more and more limited in scope. The Confucianist classics constituted the core, and a narrow and rigid interpretation prevailed. In early times, Chinese education was broad and liberal, but, by the 19th century, art, music, and science had been dropped on the wayside; even arithmetic was not accorded the same importance as reading and writing. Modern science and technology were completely neglected.

After alien rule by the Mongols the Chinese were obsessed with restoring their heritage; they avoided deviating from established forms and views. This conservatism was accentuated under Manchu rule and resulted in sterility and stagnation. The creativity and original spirit of classical education was lost. The narrow curriculum was far removed from the pressing problems and changing needs of the 19th century. (T.H.C.)

JAPAN

The ancient period to the 12th century. The Japanese nation seems to have formed a unified ancient state in the 4th century AD. Society at that time was composed of shizoku, or clans, each of which served the *chōtei* ("the imperial court") with its specialized skill or vocation. People sustained themselves by engaging in agriculture, hunting, and fishing, and the chief problem of education was how to convey the knowledge of these activities and provide instruction in the skills useful for these occupations.

Influence of Chinese and Indian civilization

The influence of the civilizations of China and India had a profound effect on both the spiritual life and the education of the Japanese. Toward the 6th century the assimilation of Chinese civilization became more and more rapid, particularly as a result of the spread of Confucianism. Buddhism was also an important intellectual and spiritual influence. Originating in India and then spreading to China, Buddhism was transmitted to Japan through the Korean peninsula in the mid-6th century.

A monarchic state system with an emperor as its head

was established following a coup d'état in 645. The subsequent Taika (Great Reform) era saw the beginning of many new institutions, most of which were primarily imitations of institutions of the T'ang dynasty of China. In the field of education, a *daigakuryō,* or college house, was established in the capital, and *kokugaku,* or provincial schools, were built in the provinces. Their chief aim was to train government officials. The early curriculum was almost identical to that of the T'ang dynasty of China but by the 8th and 9th centuries had been modified considerably to meet internal conditions, particularly as regards the educational needs of the nobility.

Through the Nara and the Heian eras (8th to 12th century), the nobility (*kuge*) constituted the ruling class, and learning and culture were the concern primarily of the *kuge* and the Buddhist monks. The *kuge* lived an artistic life, so that the emphasis of education came to be placed on poetry, music, and calligraphy. Teaching in the *daigakuryō* gradually shifted in emphasis from Confucianism to literature, since the *kuge* set a higher value on artistic refinement than on more spiritual endeavours. Apart from the *daigakuryō,* other institutions were established in which families of influential clans lodged and developed their intellectual lives.

The feudal period (1192–1867). *Education of the warriors.* Toward the mid-12th century political power passed from the nobility to the *buke,* or warrior, class. The ensuing feudal period in Japan dates from the year 1192 (the establishment of the Kamakura shogunate) to 1867 (the decline of the Tokugawa shogunate).

The warrior's way of life was quite unlike that of the nobility, and the aims and content of education in the warrior's society inevitably differed. The warrior had constantly to practice military arts, hardening his body and training his will. Education was based on military training, and a culture characteristic of warriors began to flourish. Some emphasis, though, was placed on spiritual instruction. The warrior society, founded on firm master–servant relations and centring on the philosophy of Japanese family structure, set the highest value on family reputation and on genealogies. Furthermore, because the military arts proved insufficient to enable warriors to grasp political power and thereby maintain their ruling position, there arose a philosophy of *bumbu-kembi,* which asserted the desirability of being proficient in both literary and military arts. Thus, the children of warriors attended temples and rigorously trained their minds and wills. Reading and writing were the main subjects.

Temples were the centres of culture and learning and can be said to have been equivalent to universities, in that they provided a meeting place for scholars and students. Education in the temple, originally aimed at instructing novitiates, gradually changed its character, eventually providing education for children not destined to be monks. Thus, the temples functioned as institutions of primary education.

Education in the Tokugawa era. In 1603 a shogunate was established by a warrior, Tokugawa Ieyasu, in the city of Edo (present Tokyo). The period thence to the year 1867, the Tokugawa, or Edo, era, constitutes the later feudal period in Japan. This era, though also dominated by warriors, differed from former ones in that internal disturbances finally ended and long-enduring peace ensued. There emerged a merchant class that developed a flourishing commoner's culture. Schools for commoners thus were established.

Temple schools of the Tokugawa period

Representative of such schools were the *terakoya* (temple schools), deriving from the earlier education in the temple. As time passed, some *terakoya* used parts of private homes as classrooms. Designed to be one of the private schools, or *shijuku,* the *terakoya* developed rapidly in the latter half of the Tokugawa era, flourishing in most towns and villages. Toward the end of the era they assumed the characteristics of the modern primary school, with emphasis on reading, writing, and arithmetic. Other *shijuku,* emphasizing Chinese, Dutch, and national studies, as well as practical arts, contributed to the diversification of learning and permitted students with different class and geographic backgrounds to pursue learning under the guidance of the same teacher. Their curricula were free from official control.

The shogunate established schools to promote Confucianism, which provided the moral training for upper-class samurai that was essential for maintaining the ideology of the feudal regime. *Han,* or feudal domains, following the same policy, built *hankō,* or domain schools, in their castle towns for the education of their own retainers.

The officially run schools for the samurai were at the apex of the educational system in the Tokugawa era. The Confucian Academy, which was known as the Shōheikō and was administered directly by the shogunate, became a model for *hankō* throughout Japan. The *hankō* gradually spread after about 1750, so that by the end of the era they numbered over 200.

The curriculum in the *hankō* consisted chiefly of *kangaku* (the study of books written in Chinese) and, above all, of Confucianism. Classics of Confucianism, historical works, and anthologies of Chinese poems were used as textbooks. Brush writing, *kokugaku* (study of thought originating in Japan), and medicine were also included. Later, in the last days of the shogunate, *yōgaku,* or Western learning, including Western medicine, was added in several institutions.

Both *hankō* for samurai and *terakoya* for commoners were the typical schools after the middle of the Tokugawa era. Also to be found, however, were *gōgaku,* or provincial schools, for samurai as well as commoners. They were founded at places of strategic importance by the feudal domain.

Role played by private schools

The various *shijuku* became centres of interaction among students from different domains when such close contact among residents of different areas was prohibited. They served as centres of learning and dialogue for many of those who later constituted the political leadership responsible for the Meiji Restoration of 1868.

Effect of early Western contacts. The Europeans who first arrived in Japan were the Portuguese, in 1543. In 1549 the Jesuit Francis Xavier visited Japan, and, for the first time, the propagation of Christianity began. Many missionaries began to arrive, Christian schools were built, and European civilization was actively introduced.

In 1633 the shogunate, in apprehension of further Christian infiltration of Japan, banned foreign travel and prohibited the return of overseas Japanese. Further, in 1639, the shogunate banned visits by Europeans. This was the so-called *sakoku,* or period of national isolation. From that time on Christianity was strictly forbidden, and international trade was conducted with only the Chinese and the Dutch. Because contact with Europeans was restricted to the Dutch, Western studies developed as *rangaku,* or learning through the Dutch language.

It is noteworthy that the Tokugawa period laid the foundation of modern Japanese learning. As a result of the development of *hankō* and *terakoya,* Japanese culture and education had developed to such an extent that Japan was able to absorb Western influences and attain modernization at a remarkably rapid pace after the Meiji Restoration. (A.Na./N.S.)

European Renaissance and Reformation

THE CHANNELS OF DEVELOPMENT IN RENAISSANCE EDUCATION

The Muslim influence. Western civilization was profoundly influenced by the rapid rise and expansion of Islām from the 7th until the 15th century. By 732, 100 years after the death of Muḥammad, Islām had expanded from western Asia throughout all of northern Africa, across the straits of Gibraltar into Spain, and into France, reaching Tours, halfway from the Pyrenees to Paris. Muslim Spain rapidly became one of the most advanced civilizations of the period, where much of the learning of the past—Oriental, Greek, and Roman—was preserved and further developed. In particular, Greek and Latin scholarship was collected in great libraries in the splendid cities of Córdoba, Seville, Granada, and Toledo, which became major centres of advanced scholarship, especially in the practical arts of medicine and architecture.

Inevitably, scholarship in the adjacent Frankish, and subsequent French, kingdom was influenced, leading to a revitalization of western Christian scholarship, which had long been dormant as a result of the barbarian migrations. The doctrines of Aristotle, which had been assiduously cultivated by the Muslims, were especially influential for their emphasis on the role of reason in human affairs and on the importance of the study of humankind in the present, as distinct from the earlier Christian preoccupation with the cultivation of faith as essential for the future life. Thus, Muslim learning helped to usher in the new phase in education known as humanism, which first took definite form in the 12th century.

Humanism

The secular influence. The word humanism comes from *studia humanitatis* ("studies of humanity"). Toward the end of the Middle Ages there was a renewed interest in those studies that stressed the importance of man, his faculties, affairs, worldly aspirations, and well-being. The primacy of theology and otherworldliness was over; the *reductio artium ad theologiam* (freely, "reducing everything to theological argument") was rejected since it no longer expressed the reality of the new situation that was developing in Europe, particularly in Italy. Society had been profoundly transformed, commerce had expanded, and life in the cities had evolved. Economic and political power, previously in the hands of the ecclesiastical hierarchy and the feudal lords, was beginning to be taken over by the city burghers. Use of the vernacular languages was becoming widespread. The new society needed another kind of education and different educational structures; the burghers required new instruments with which to express themselves and found the old medieval universities inadequate.

The educational institutions of humanism had their origin in the schools set up in the free cities in the late 13th and the 14th centuries—schools designed to answer to the needs of the new urban population that was beginning to have greater economic importance in society. The pedagogical thought of the humanists took these transformations of society into account and worked out new theories that often went back to the classical Greek and Latin traditions; it was not, however, a servile imitation of the pedagogical thought and institutions of the classical world.

The Renaissance of the classical world and the educational movements it gave rise to were variously expressed in different parts of Europe and at various times from the 14th to the 17th century; there was a connecting thread, but there were also many differences. What the citizens of the Florentine republic needed was different from what was required by princes in the Renaissance courts of Italy or in other parts of Europe. Common to both, however, was the rejection of the medieval tradition that did not belong in the new society they were creating. Yet the search for a new methodology and a new relation with the ancient world was bitterly opposed by the traditionalists, who did not want renewal that would bring about a profound transformation of society; and, in fact, the educational revolution did not completely abolish existing traditions. The humanists, for example, were not concerned with extending education to the masses but turned their attention to the sons of princes and rich burghers.

The humanists had the important and original conception that education was neither completed at school nor limited to the years of one's youth but that it was a continuous process making use of varied instruments: companionship, games, and pleasure were part of education. Rather than suggesting new themes, they wanted to discover the method by which the ancient texts should be studied. For them knowledge of the classical languages meant the possibility of penetrating the thought of the past; grammar and rhetoric were being transformed into philological studies not for the sake of pedantic research but in order to acquire a new historical and critical consciousness. They reconstructed the past in order better to understand themselves and their own time.

THE HUMANISTIC TRADITION IN ITALY

Early influences. One of the most influential of early humanists was Manuel Chrysoloras, who came to Florence from Constantinople in 1396. He introduced the study of Greek and, among other things, translated Plato's *Republic* into Latin, which were important steps in the development of the humanistic movement.

Inspired by the ancient Athenian schools, the Platonic Academy established in Florence in the second half of the 15th century became a centre of learning and diffusion of Christian Platonism, a philosophy that conceived of all forms as the creative thoughts of God and that inspired considerable artistic innovation and creativity. Marsilio Ficino and Pico della Mirandola were two of the most original of the scholars who taught there. Florence was the first city to have such a centre, but Rome and Naples soon had similar academies, and Padua and Venice also became centres of culture.

A famous early humanist and professor of rhetoric at Padua was Pietro Paolo Vergerio (1370–1444). He wrote the first significant exclusively pedagogical treatise, *De ingenuis moribus et liberalibus studiis* ("On the Manners of a Gentleman and on Liberal Studies"), which, though not presenting any new techniques, did set out the fundamental principles by which education should be guided. He gave pedagogical expression to the ideal of harmony, or equilibrium, found in all aspects of humanism, and underlined the importance of the education of the body as well as of the spirit. The liberal arts were emphasized ("liberal" because of the liberation they reputedly brought); the program outlined by Vergerio focused upon eloquence, history, and philosophy but also included the sciences (mathematics, astronomy, and natural science) as well as medicine, law, metaphysics, and theology. The later subjects were not studied in depth; humanism was by its nature against encyclopaedism, but it brought out the relations between the disciplines and enabled students to know many subjects before they decided in which to specialize. Learning was not to be exclusively from books, and emphasis was placed on the advantages of preparing for social life by study and discussion in common. Vergerio felt that education should not be used as a means of entering the lucrative professions; medicine and law, especially, were looked on with suspicion if one's aim in studying them was merely that of gaining material advantages.

Emphasis on the liberal arts

Emergence of the new gymnasium. As a result of the renewed emphasis on Greek studies, early in the 15th century a definite sequence of institutions emerged, with the gymnasium as the principal school for young boys, preparatory to further liberal studies in the major nonuniversity institution of higher learning, the academy. Both terms, gymnasium and academy, were classical revivals, but their programs were markedly different from those of ancient Greece. The gymnasiums appeared in ducal courts; they were created for the liberal education of privileged boys and as the first stage of the *studia humanitatis*. Outstanding among these early gymnasiums were the school conducted by Gasparino da Barzizza in Padua from 1408 to 1421, considered a model for later institutions, and more particularly the gymnasium of Guarino Veronese (1374–1460) and that of his contemporary Vittorino da Feltre (1378–1446).

Guarino had first established a school in 1415 in Venice, where he was joined by Vittorino. He subsequently moved to Ferrara where, from 1429 to 1436, he assumed responsibility for the humanist education of the young son of Nicolò d'Este, the lord of Ferrara. Guarino wrote no treatises, but something may be learned about his work and methods from his large correspondence and from *De ordine docendi et studendi* (1485; "On the Order for Teaching and Studying"), written by his son Battista. Guarino organized his students' courses into three stages: the elementary level, at which reading and pronunciation were primarily taught, followed by the grammatical level, and finally the highest level, concentrating on rhetoric. The education given in his schools was perhaps the best example of the humanistic ideals, since it underlined the importance of literary studies together with a harmonious development of body and spirit, to the exclusion of any utilitarian purpose.

Humanist de-emphasis of "useful" education

Vittorino was a disciple of both Barzizza and Guarino. He conducted boarding schools at Padua and Venice and,

most importantly, from 1423 to 1446 one at Mantua, where he had been invited by the reigning lord, Gianfrancesco Gonzaga. This last school, known as La Giocosa (literally, "The Jocose, or Joyful"), soon became famous. At La Giocosa only those who had both talent and a modest disposition were accepted; wealth was neither necessary nor sufficient to gain admission; in fact, the school was one of the few efforts made during this period to extend education to a wider public. The program of study at La Giocosa was perhaps closer to the medieval tradition than that of the other boarding schools, but, in any case, the spirit was different. Studies were stimulating; mathematics was taught pleasantly—Vittorino going back to very ancient traditions of practicing mathematics with games. After having studied the seven arts of the trivium (grammar, rhetoric, and logic) and the quadrivium (geometry, arithmetic, harmonics, and astronomy), students completed the cycle by a study of philosophy and then, having mastered this discipline, could go on to higher studies leading to such professions as medicine, law, philosophy, and theology. Italian was completely ignored at Vittorino's school; all instruction was given in Latin, the study of which, together with Greek, reached a high level of excellence. Great importance was given to recreation and physical education; his concern for the health of his students did not come to an end with the scholastic year, for during the summers, when the cities became unhealthy, he would arrange for his students to go to Lake Garda or to the hills outside Verona.

Vittorino's educational philosophy was inspired by a profound religious faith and moral integrity, which contrasted with the general relaxation of standards within the church itself; but, if he was severe with himself, he was very open and tolerant with his pupils. The school continued only for a while after his death because, more than in the case of the other schools, La Giocosa was identified with the personality of the founder.

Nonscholastic traditions. Leon Battista Alberti, one of the most intelligent and original architects of the 15th century, also dedicated a treatise, *Della famiglia* (1435–44; "On the Family"), to methods of education. Alberti felt that the natural place for education was the home and not scholastic institutions. The language in which he wrote was Italian, education being in his view so important in social life that he felt that discussion of it should not be limited to scholars. He stressed the importance of the father in the educational process.

Baldassare Castiglione expressed the transition of humanism from the city to the Renaissance court. He himself was in the service of some of the most splendid princes, the Gonzagas at Mantua and the Montefeltros at Urbino. Just as in the 15th century the humanists had been concerned with the education of the city burgher, so in the 16th century they turned their attention to the education of the prince and of those who surrounded him. *Il cortegiano* ("The Courtier") was published in 1528, and within a few years it had been translated into Latin and all the major European languages. The courtier was to be the faithful collaborator of the prince. He had to be beautiful, strong, and agile; he had to know how to fight, play, dance, and make love. But this was not all, since great importance was also attached to the study of the classics and the practice of poetry and oratory; the courtier had to be able to write in rhyme and in prose and have perfect command of the vernacular, which was becoming important in political affairs; but above all he had to have skill at arms.

Education of the courtier

The courtier described by Castiglione, though in the service of necessarily devious princes, had to know how to keep his dignity and his virtue. Castiglione's moral standards, reflecting the spiritual climate at Urbino, completely disappeared, however, in Giovanni della Casa's work, *Galateo* (1551–54), in which considerations of etiquette were placed above all others; the values of humanism no longer existed, and all that was left was ceremonial.

THE HUMANISTIC TRADITION OF NORTHERN AND WESTERN EUROPE

The economic and social conditions behind the intellectual and cultural revolution of humanism in Italy were also present, though in different forms, in other parts of Europe. In some states, chiefly England, France, and Spain, humanism and educational reforms developed around the courts, where political power was being concentrated; in others, such as the Netherlands, they were brought about by the city burghers, whose power, both economic and political, was increasing. The educational reforms that the humanists brought about in northern and western Europe developed slowly, but on the whole they were lasting, since they affected a greater number of people than was the case in Italy, where they tended to be restricted to a narrow circle of families. There were close relations between Italian and other European educational humanists, as there were among English, Dutch, French, and German humanists, and, thus, national differences were not so significant.

Courtly and bourgeois forms of humanism

Dutch humanism. In the Netherlands the ground for educational reform had already been prepared in the 14th century by the Brethren of the Common Life, a group founded by Gerhard Groote to bring together laymen and religious men. Although their work was not originally in the field of education, education started when they set up hostels for students and exercised some moral direction over these students; this work was extended, and the Brethren eventually set up schools, first at Deventer, then in other cities. Some of the most important humanists of the Netherlands and Germany attended their schools—among others, Erasmus.

The school at Deventer came to have great prestige under Alexander Hegius, rector from 1465 to 1498 and author of a polemic treatise, *De utilitate Graeci* ("On the Usefulness of Greek"), underlining the importance of studying Greek, and of *De scientia* ("On Knowledge") and *De moribus* ("On Manners"). Hegius had great talent as an organizer and succeeded not only in attracting some of the best scholars of the time but also in giving the school an efficient structure that became a model for many schools in the north.

Desiderius Erasmus was a great scholar and educator, and his influence was felt all over Europe. His strong personality earned him the respect and sympathy of humanists who saw in him, as in few others, the symbol of their ideals and values. Unfortunately, his proposals for reform and greater tolerance were not always accepted in the tortured Europe of the 16th century.

Erasmus was a prolific writer, and part of his work was concerned with education: *De ratione studii* (1511; "On the Right Method of Study"), *De civilitate morum puerilium* (1526; "On the Politeness of Children's Manners"), *Ciceronianus* (1528), *De pueris statim ac liberaliter instituendis* (1529; "On the Liberal Education of Boys from the Beginning"). His educational program was original in many ways but in no sense democratic. The masses could not partake in higher education, since their aim was that of gaining skill in an occupation. He felt that religious instruction should be made available to all but that classical literary studies—the most important of all studies—were for a minority.

The classical and elitist tradition in humanism

Study of ancient languages and intelligent comprehension of texts formed the basis of Erasmus' system of education; he took a stand against the formalism and dogmatism that were already creeping into the humanist movement. Erasmus was in favour of acquiring a good general liberal arts education until the age of 18, being convinced that this would be a preparation for any form of further study. His great love for the classical languages, however, made him neglect the vernacular; he was not interested in local traditions; and he attributed very little importance to science, which he did not think necessary for a cultured man. He was against instruction being imposed without the participation of the student. His optimism about the nature of man and the possibilities of molding him made Erasmus feel that, if adequately educated, any man could learn any discipline. He further sought renewal of the schools and better training for teachers, which he felt should be a public obligation, certainly no less important than military defense. Many of Erasmus' themes were elaborated a century later by John Amos Comenius and form the basis of modern education, in particular the effort to understand the child psychologically and to consider education

as a process that starts before the school experience and continues beyond it.

Juan Luis Vives. Strongly influenced by Erasmus was Juan Luis Vives, who, though of Spanish origin, spent his life in various parts of Europe—Paris, Louvain, Oxford, London, Bruges. His most significant writings were *De institutione foeminae Christianae* (1523; "On the Education of a Christian Woman"), *De ratione studii puerilis* ("On the Right Method of Instruction for Children"), *De subventione pauperum* (1526; "On Aid for the Poor"), and *De tradendis disciplinis* (1531; "On the Subjects of Study").

The new social and utilitarian traditions

Not only was his vision of the organic unity of pedagogy new, but he was the first of the humanists to emphasize the importance of popular education. He felt that it was the responsibility of the city to provide instruction for the poor and that the craft and merchant guilds had an important contribution to make to education. Unlike other humanists, moreover, he did not despise the utilitarian aspects of education but on the contrary suggested that his pupils should visit shops and workshops and go out into the country to learn something of real life.

Just as he felt that education should not be limited to a single social class, so he felt that there should be no exclusion of women, though perhaps they required a different kind of education because of their different functions in life.

Vives worked out a plan to take account of both educational structures and teacher training. In emphasizing the social function of education, he was against schools being run for profit and believed that teachers should be prepared not only in their specific fields but also in psychology so as to understand the child. He also suggested that teachers should meet four times a year to examine together the intellectual capacities of each one of their pupils so that suitable programs of study could be arranged for them. Vives considered that, in teaching, games had psychological value. He favoured use of the vernacular for the first stage of education; but, as a humanist, he had a passion for Latin and felt that there was no substitute for Latin as a universal language. Classical studies were to be completed by investigation of the modern world, in particular its geography, the horizons having been greatly enlarged by recent discoveries. Vives' method was an inductive one, based not on metaphysical theories but on experiment and exercise.

The early English humanists. At the end of the 15th century there was a flowering in England of both humanistic studies and educational institutions, enabling a rapid transition from the medieval tradition to the Renaissance. The English humanists prepared excellent texts for studying the classical languages, and they started a new type of grammar school, long to be a model. Most important were John Colet and Thomas More. Thomas Linacre, author of *De emendata structura Latini sermonis libri sex* (1524; "Six Books on the Flawless Structure of the Latin Language"), should also be remembered, as well as William Lily, author of a Latin syntax, *Absolutissimus de octo orationis partium constructione libellus* (1515; "Comprehensive Study of the Construction of the Eight Parts of Speech"), and director of St. Paul's School in London from 1512 to 1522.

The English grammar schools

Colet has an important place in English education. As dean of St. Paul's Cathedral he founded St. Paul's School, thus favouring the introduction of humanism in England and the transformation of the old ecclesiastical medieval schools. He had traveled a great deal in France and Italy and wanted to bring to his country the humanistic culture that had so fascinated him. In 1510 he started a "grammar school," open to about 150 scholars who had an aptitude for study and had completed elementary school. Colet's personality and energy made his school a lively centre of English humanism.

More was both a distinguished humanist and a statesman. He was interested in pedagogy, to which he dedicated part of his work *Utopia* (1516). In his Utopia, More saw the connection between educational, social, and political problems and the influence that society therefore has on education. English humanists such as More were engaged in a bitter battle because medieval tradition was deeply rooted; they were fierce opponents of a group called the Trojans, who opposed the Greek language and all that the new instruction of that language represented.

EDUCATION IN THE REFORMATION AND COUNTER-REFORMATION

New political and social systems developed in those European countries that, for various reasons and at different times, broke away from the Roman Catholic church in the 16th century. The religious reforms brought about by Martin Luther, John Calvin, Huldrych Zwingli, and the ruling family of England were both cause and effect of these transformations. Characteristic of all these countries was the importance of the state in the organization of the educational system.

The Reformation and European humanism influenced one another. There were analogies between the flowering of the classical world in the European courts and the reawakening of religious interests; there were similarities in the critical position adopted toward Aristotelianism and in the interest shown toward the study of classical languages, such as Greek and Hebrew. The presuppositions behind the two movements—humanism and Reformation—were different, however, and sooner or later a clash was inevitable. The most spectacular of these clashes was between Erasmus and Luther, despite the fact that for a long time they had respected each other. It was important for Erasmus and for the humanists to encourage the development of a world of writers and artists who, free from material preoccupations, could devote their time to literary and artistic pursuits. For the Reformers the situation was different: they did not aim to educate a small minority; unlike Erasmus, Luther had to keep the masses in mind, for they had contributed to the success of the religious reforms.

Humanism and the Reformation

Luther and the German Reformation. Luther specifically wished his humble social origins to be considered a title of nobility. He wanted to create educational institutions that would be open to the sons of peasants and miners, though this did not mean giving them political representation. (The German princes were glad to promote the Reformation on condition that it would not diminish but would, on the contrary, increase their political power.) Luther realized that an educational system open to the masses would have to be public and financed by citizens' councils. His educational programs are set out in *An die Radsherrn aller Stedte deütsches Lands: Das sie christliche Schulen affrichten und hallten sollen* (1524; "Letter to the Mayors and Aldermen of All the Cities in Behalf of Christian Schools"), in *Dass man Kinder zur Schulen halten solle* (1530; "Discourse on the Duty of Sending Children to School"), and in various letters to German princes.

Although Luther advocated the study of classical languages, he believed that the primary purpose of such an education, in marked distinction to the aims of the humanists, was to promote piety through the reading of the Scriptures in their pure form. "Neglect of education," Luther wrote in a letter to Jacob Strauss in 1524, "will bring the greatest ruin to the Gospel." Accordingly, Luther argued that education must be extended to all children, girls as well as boys, and not simply to a leisured minority as in Renaissance Italy. Even those children who had to work for their parents in trade or in the fields should be enabled, if only for a few hours a day, to attend local, city-maintained schools in order to promote their reading skills and hence piety. Out of the Lutheran argument emerged a new educational concept, the *pietas litterata:* literacy to promote piety.

Lutheran emphasis on public schools for all

On the premise that a new class of cultivated men must be developed to substitute for the dispossessed monks and priests, new schools, whose upkeep was the responsibility of the princes and the cities, were soon organized along the lines suggested by Luther. In 1543 Maurice of Saxony founded three schools open to the public, supported by estates from the dissolved monasteries. It was more difficult to set up the city schools, for which there was no tradition. In towns and villages of northern Germany Johannes Bugenhagen (1485–1558) set up the earliest schools to teach religion and reading and writing in German, but it was

not until 1559 that the public ordinances of Württemberg made explicit reference to German schools in the villages. This example was shortly followed in Saxony.

Whereas Luther combined his interest in education with his work as a religious reformer and politician, another Reformer, Philipp Melanchthon (1497–1560), concentrated almost entirely on education, creating a new educational system and, in particular, setting up a secondary-school system. He taught for many years at the University of Wittenberg, which became one of the centres of theological studies in Reformation Germany; and his experience there enabled him to reorganize the old universities and set up new ones, such as Marburg, Königsberg, and Jena. His ideas about secondary education were put into practice in the schools he founded at Eisleben. Scholastic work was divided into three stages, access to each successive stage depending on the ability of the student to master the previous course work; this was a new concept (foretelling the later "grading system"), unknown in the traditional scholastic system. He was convinced that too many subjects should not be imposed on the student. He felt that Latin was important but not German, Greek, or Hebrew, as had been taught in the humanistic schools; such variety, he felt, was exhausting and possibly harmful. This opened the door to a new type of formalism, however, a danger that in other spheres the educational reformers had tried to fight.

Growing formalism in German schools

The work of Johannes Sturm (1507–89) illustrates this danger. He founded a grammar school in Strassburg (now Strasbourg, Fr.) that became a model for German schools. Sturm believed that methods of instruction in elementary schools and, to some degree, in secondary schools should be different from those in the institutes of higher education. Not much autonomy was to be allowed the child, who started learning Latin at the age of six by memorizing. Sturm's love of Latin was even greater than that of his friend Erasmus, who never wanted it to become a mechanical exercise. As a consequence, German was neglected, as was physical instruction, and too much importance was given to form and expression for its own sake.

The English Reformation. The separation of the Church of England from the church of Rome in the 16th century under Henry VIII did not have quite the repercussions in the scholastic field that were experienced by the continental Reformations. The secondary-school system in England had been strongly influenced by the Renaissance in the period preceding the reform, and about 300 grammar schools were already in existence. Nevertheless, the situation became precarious, for political reasons, under a succession of sovereigns.

Henry VIII included the schools in his policy of concentration and consolidation of power in the hands of the state. In 1548, under Henry's son Edward VI, the Chantries Act was passed, confiscating the estates of the church expressly for use in education; but the turmoil of the times, under the boy Edward and then his Roman Catholic sister Mary I, allowed the funds allocated to education to be diverted elsewhere. Many primary schools and grammar schools disappeared or retrenched their operations for lack of funds. Elizabeth I, however, succeeding to the throne in 1558, revived Henry VIII's educational policy; considerable sums were appropriated for education, even though it was not always possible to enforce the new provisions because of local opposition and some lack of concern on the part of the Anglican clergy.

The growth of a rich and prosperous mercantile class and the spread of Calvinist reforms through the Puritans in England and the Presbyterians in Scotland were also factors in the transformation of English education in the 16th and 17th centuries. Scholastic programs reflected changes in society: importance was given to English, to science, to modern languages (in particular French and Italian), and to sports, as is still the case in England today. The Puritan contribution was thus considerable, though often hindered by the traditional forces of the Anglican church and the old nobility.

The work of Sir Thomas Elyot and Roger Ascham

Sir Thomas Elyot, in *The Boke Named the Governour* (1531), wrote the first treatise in English that dealt specifically with education. He was interested in those who would have the future economic and political power in their hands. Though their education was to include the classics, it was to be supplemented by the needs of the new mercantile class—the national English language, manual arts, drawing, music, and all forms of sport. Elyot was obviously influenced by Erasmus.

Roger Ascham was close in thought to many of the English humanists. In *The Scholemaster* (1570) he underlined the importance of the English language (in spite of his being a professor of Greek) and proposed that it should be used in teaching the classical languages. He also believed that physical exercise and sport were important, not only for the nobility and the leisured classes but also for students and teachers. He was aware of the social changes in the country; and, observing with sadness the corruption of the new wealth, he was particularly chagrined to see students going to university not to gain culture but to prepare themselves for high offices of state.

Richard Mulcaster had 30 years of experience as an educator at St. Paul's School and at the Merchant Taylors School, a Latin secondary school maintained by the tailors' guild in London—and most famous of all the "guild schools." Mulcaster was in favour of efficient teacher training and of teachers being adequately paid. In agreement with some of the Lutheran educational reforms, he felt that schools should be open to all, including women, who should moreover have access to higher education. He is particularly remembered for his opposition to Italianate trends: "I love Rome, but London better. I favour Italy, but England more. I know the Latin, but worship the English."

Sir Francis Bacon was interested in education though it was not his main concern—his main concern being the championship of the scientific method and "sense" realism, or empiricism, in opposition to traditional Aristotelianism and Scholasticism. He was opposed to private tutors and felt that boys and youths were better off in schools and that their education should be geared to their social status and future activity. Schooling should aim at preparing statesmen and men of action as well as scholars and thus should include history, modern languages, and politics. Bacon himself had a passion for study not only for its utilitarian purposes but because of its being for him a true source of delight.

The French Reformation. Schools in 16th-century France were still largely under the control of the Roman Catholic church, as they had been in the Middle Ages. This traditional education faced opposition, however, both from Protestants and from reformers who had been influenced by the humanist principle of the primacy of the individual.

Reformers opposed to traditional education

François Rabelais was a great and original interpreter of humanistic ideals, and his views on education reflected this. He himself studied in various fields, from medicine to letters, and was passionately interested in all of them. His controversy with the Sorbonne, a remaining stronghold of medievalism and Scholasticism, was bitter; he satirized the school and the useless notions taught there in his novels *Pantagruel* (1532) and *Gargantua* (1534).

Rabelais's educational philosophy was entirely different from that of the medievalists—his being based on liberty of the pupil, in whom he had maximum faith. In *Gargantua* this cult of liberty was celebrated in the utopian Abbey of Thélème, where all could live according to their own pleasure but where the love of learning was so great that everyone was dedicated to it, getting much better results than those obtained at the medieval universities. And yet in the education of Gargantua and Pantagruel there were limits placed on liberty: Gargantua's day started at 4 in the morning; he studied all subjects, both literary and scientific; and this was alternated with play and pleasing diversions. The heavy program, however, was not a constriction because of Gargantua's delight in learning. The culture that Rabelais wanted for his two heroes was directly connected with the world in which they lived.

Gargantua and *Pantagruel* were perhaps among the first texts by a humanist in which not only the quadrivium but also scientific studies were enthusiastically proposed. There was nothing arid or abstract in Rabelais's approach

to nature, and in this context the classics also had a new flavour: ancient literature, no longer limited to Latin, Greek, and Hebrew but expanded to include Arabic and Chaldaic, could bring to light valuable knowledge that had been accumulated by the classical world.

Petrus Ramus, one of the most bitter critics of French medieval Aristotelianism, was an intelligent reformer of educational methods. His best-known treatises are *Aristotelicae animadverstiones* (1543; "Animadversions on Aristotle") and *Dialecticae partitiones* (1543; "Divisions of Dialectic"), both condemned by royal decree; he also wrote two discourses on philosophy, *Oratio de studiis philosophiae et eloquentiae conjungendis* (1546; "Speech on Joining the Study of Philosophy with the Art of Speaking") and *Pro philosophica Parisiensis accademiae disciplina oratio* (1551; "Speech in Defense of the Philosophical Discipline of the Parisian Academy"), as well as *Ciceronianus,* published posthumously. In these works his criticism of traditional ways and of the degeneration of humanistic thought made him hated by all Roman Catholics, though not much better understood by Protestants; he died a Protestant victim of the massacre of St. Bartholomew. His program of study was fairly close to the traditional one, but his method was original, for he was concerned that the teacher should not suffocate the child with too many lessons and considered the child's autonomous activity important. He especially resented any pedagogy that relied on a blind appeal to authority; learning had to be utilitarian and issue from practice.

Michel de Montaigne (1533–92) was much influenced by his personal experience as a student. Though often critical of humanism, especially when it was misinterpreted and transformed into pedantic studies, he had great admiration for the classics and lacked the scientific interests of Rabelais or Ramus. Montaigne wrote specifically about education in two essays on the upbringing of children and on pedantry. Culture, he felt, had become imitation, often with no trace of originality left, whereas it should be a delight—not something a student is forced to assimilate but something to draw the student's participation. He was in favour of instruction by tutors capable of giving the student individual attention—the ideal tutor being one with a good mind rather than one filled with pedantic notions. He also believed in the importance of physical education and in a boy's being hardened to nature and to danger.

For Montaigne it was important not only to travel to foreign countries but also to stay there for a while, to learn languages and, even more, to learn about foreign customs and thus break out of the narrow limits of one's own province. There were many differences between Montaigne and Erasmus, but both were convinced that for the wise man there could be no geographic boundaries, for, through cultural diffusion, barriers would be broken down.

The Calvinist Reformation. The Protestant Reformer John Calvin was of French origin, but he settled in Geneva and made this Swiss city one of the most prominent centres of the Reformation. Unlike Luther, whose reforms were backed by princes hoping to gain greater political independence, Calvin was supported by the new mercantile class, which needed political and administrative changes for the purposes of its own expansion.

Calvin considered popular education important, but he was not an innovator. The theological academy he founded in Geneva in 1559 was modeled on Sturm's school in Strassburg, where Calvin had taught; it became distinguished under the directorship of Theodore Beza, an intelligent Reformer but unfortunately a very intolerant one, at least in theological matters. Calvin's influence on education was nevertheless felt in many of the European universities, even as far as England, where, in spite of Anglican opposition, the Puritans had gained a foothold.

Calvinist emphasis on universal literacy

Calvin was in favour of universal education under church control (the cost to be in large part borne by the community), but "universal" did not mean "democratic." Even if some form of instruction was to be given to everyone (so that everyone might in some measure read the Scriptures for himself, in good Calvinist tradition), very few individuals reached secondary or higher education, and of these only a minute percentage came from the working classes. Documents of the period show the steps taken to achieve the aim of universal education. In the Netherlands, the Calvinist Synod of The Hague in 1586 made provision for setting up schools in the cities, and the Synod of Dort in 1618 decreed that free public schools should be set up in all villages. In Scotland in 1560 John Knox, a disciple of Calvin and the leader of the Scottish Presbyterians, aimed at setting up schools in every community, but the nobility prevented this from actually being carried out. The major educational contributions of Calvinism were its diffusion to a larger number of people and the development of Protestant education at the university level. Not only was Geneva significant but also the universities of Leiden (1575), Amsterdam (1632), and Utrecht (1636) in the Netherlands and the University of Edinburgh (1582) in Scotland. The Puritan, or English Calvinist, movement was responsible for the founding of Emmanuel College at the University of Cambridge (1584).

The Roman Catholic Counter-Reformation. The religious upheaval, so important in northern Europe, also affected, though less violently, the Latin countries of southern Europe. If the new ferment in the Roman Catholic church was mainly directed at answering the Protestants, at times it also had something original to suggest. At the Council of Trent (1545–63) the Roman Catholic church tried to come to terms with the new political and economic realities in Europe.

Education was foremost in the minds of the leaders of the Counter-Reformation. The faithful were to be educated. For this, capable priests were needed, and, thus, seminaries multiplied to prepare the clergy for a more austere life in the service of the church. There was a flowering of utopian ideas, which should be remembered when trying to understand unofficial Catholic thought of the period. Writings such as *La città del sole* ("The City of the Sun"), by Tommaso Campanella, and *Repubblica immaginaria* ("The Imaginary Republic"), by Lodovico Agostini, are examples of this new vision of the church and of the duties of Christians. But if in the minds of the utopians this education was to be universal, it was in fact almost entirely directed at the ruling classes.

The growth of seminaries

The Society of Jesus, founded in 1534 by Ignatius Loyola, was not specifically a teaching order, but it was nevertheless very important in this field. The first Jesuit college was opened in Messina, Sicily, in 1548; by 1615 the Jesuits had 372 colleges, and by 1755, just 18 years before the suppression of the order, the number had risen to 728. (The society was not reestablished until 1814.) In *Ratio studiorum,* an elaborate plan of studies issued by the Jesuits in 1599, there is laid out an organization of these institutions down to the smallest details; an authoritarian uniformity was thus the rule in their colleges, and individual initiative was discouraged. The complete course of study took at least 13 years, divided into three periods: six or more years that included grammar and rhetoric, three years of philosophy, and four of theology. The teacher was thought of not only as an instructor but also as an educator and often a controller, for he was at the centre of a vast network of controls, in which those students considered promising also took part. Emulation was encouraged in the class, which was often divided into two groups to stimulate competition. These new techniques, as well as the Jesuits' efficient training of teachers, had good results, proof of this being the rapid increase in their colleges, which found greater favour than others started in the same period.

The legacy of the Reformation. The effects on education of a movement as complex and widespread as the Reformation were far-reaching. Perhaps its most original contribution was the extension of the idea of education at the elementary level. As a result, the vernacular language took on a new importance, and also the new pedagogy had to take account of the realities of the situation—namely, that the children brought into the new school network could not spend as much time on "useless" books, so that schoolwork had to be combined with learning a practical trade, which had not previously been considered a part of education. This, however, was to take several centuries to be implemented in practice. (E.Ge./J.Bo.)

European education in the 17th and 18th centuries

THE SOCIAL AND HISTORICAL SETTING

The Renaissance had been the beginning of a new era in history, which culminated in the 17th and 18th centuries in the development of the absolutist state everywhere but in England and Holland (and even in these states the issue was for some time in doubt). France, the Habsburg empire, England, and Russia became the leading powers in Europe. The absolutist state extended its control beyond the political and into the religious (with the creation of the established church) and into almost all other aspects of human life. Although the High and later Middle Ages had witnessed the growth of middle-class forces, the pattern of society still clearly bore the stamp of court life. The concentration of power determined this life, and the citizen and his possessions were more and more at the disposal of the aristocracy. The citizen was subject.

Influence of absolutism on education

Even in an absolutist state, however, education cannot be the sole privilege of the rich or the ruling classes, because an efficient absolutist state requires capable subjects, albeit bound to their social position. Elementary education for the middle classes thus developed in the 17th and 18th centuries, and more and more the state saw as its task the responsibility for establishing and maintaining schools. This tendency toward general education did not stem only from considerations of political expediency; it stemmed also from the desire to improve the world through education—making all areas of life orderly and subordinate to rational leadership. There was not only an inclination toward encyclopaedism and systemization of the sciences but also, in similar fashion, a tendency to set education aright by extensive school regulations.

In general, this distinction can be made between the 17th and the 18th centuries: in the 17th century the aim of education was conceived as a religious and rationalistic one, whereas in the 18th century the ideas of secularism and progress began to prevail. The 18th century is especially remembered for three leading reforms: teaching in the mother language grew in importance, rivaling Latin; the exact sciences were brought into the curriculum; and the correct methods of teaching became a pedagogic question.

The new scientism and rationalism. These social and pedagogic changes were bound up with new tendencies in philosophy. Sir Francis Bacon of England was one who criticized the teachers of his day, saying that they offered nothing but words and that their schools were narrow in thought. He believed that the use of inductive and empirical methods would bring the knowledge that would give man strength and make possible a reorganization of society. Therefore, he demanded that schools should be scientific workplaces in the service of life and that they should put the exact sciences before logic and rhetoric.

Another 17th-century critic of medievalism was René Descartes, but he did not proceed from empirical experience, as did Bacon; for him the only permanence and certainty lay in human reason or thinking (*cogito ergo sum,* "I think; therefore, I am"). The ability to think makes doubt and critical evaluation of the environment possible. A science based only on empiricism fails to achieve any vital, natural explanations but only mathematical, mechanistic ones of doubtful living use. Only what reason (*ratio*) recognizes can be called truth. Thus, education must be concerned with the development of critical rationality.

Knowledge conceived as thinking

Like Descartes, Benedict de Spinoza and Gottfried Wilhelm Leibniz also outlined rationalistic philosophic systems. Decisive for educational theory was their statement that knowledge and experience originate in thinking (not in sense impressions, which can provide only examples and individual facts) and that formal thinking categories should form the substance of education. They believed that the aim of education should be the mastery of thinking and judgment rather than the mere assimilation of facts.

The Protestant demand for universal elementary education. The schools that were actually developed fell short of these philosophically based demands. This is especially true of elementary education. In the Middle Ages, the grammar schools (especially for the education of the clergy) had developed, and the humanism of the Renaissance had strengthened this tendency; only those who knew Latin and Greek could be considered educated. For basic, popular education there were meagre arrangements. Although schools for basic writing and arithmetic had been established as early as the 13th and 14th centuries, they were almost exclusively in the towns; the rural population had to be content with religious instruction within the framework of the church. This changed as a result of Protestantism. John Wycliffe had demanded that everyone become a theologian, and Luther, by translating the Holy Scriptures, made the reading of original works possible. Everyone, he asserted, should have access to the source of belief, and all children should go to school. So it happened that church regulations of the 16th and 17th centuries began to contain items governing schools and the instruction of young people (mainly in reading and religion). At first, the Protestant schools were directed and supported almost entirely by the church. Not until the 18th century, following the general tendency toward secularization, did the state begin to assume responsibility for supporting the schools.

EDUCATION IN 17TH-CENTURY EUROPE

Central European theories and practices. It was while Europe was being shaken by religious wars and was disintegrating into countless small states that such writers as Campanella and Bacon dreamed their Utopias (*La Città del sole* and the *New Atlantis,* respectively), where peace and unity would be had through logical and realistic means. To even attempt realizing this dream, however, man needed suitable education. Both leading representatives of so-called pedagogic realism, Wolfgang Ratke and John Amos Comenius, were motivated by this ideal of world improvement through a comprehensive reform of the school system. Despite this common starting point, however, both were highly distinct personalities and, moreover, had divergent influences on the development of education and schools.

Realism in education

The pedagogy of Ratke. Ratke (1571–1635), a native of Holstein in Germany, journeyed to England, Holland, and through the whole of Germany and to Sweden expounding his ideas to the political authorities and finding considerable support. His plans for progressive reform failed for several reasons. First, political conditions during the Thirty Years' War were understandably not favourable for any kind of planning or reform of schools. Moreover, Ratke demonstrated little practical ability in executing his plans. Finally, Ratke's ideas were not free of exaggerations. He promised, for example, to be able to teach 10 languages in five years, each language in six months.

His ideas about the art of teaching are, nevertheless, of importance for the theory and practice of education. First, he believed that knowledge of things must precede words about things. This "sense realism" means that individual experience in contact with reality is the origin of knowledge; principles of knowledge follow, rather than precede, the study of specifics.

Second, everything must follow the order and course of what may be called human nature. In modern terms, one would say that a lesson should be designed with psychological conditions taken into consideration.

Third, he asserted that everything should be taught first in the mother language, the mother language being the natural and practical language for children and the one that allows them to concentrate wholly on the business at hand. Only when the mother language is fully commanded should a child attempt a foreign language; then special attention should be paid to speaking it and not merely reading it.

Fourth, Ratke emphasized what might now be called a kind of programmed learning. One piece of work should be fully completed before progress is made to the next piece, and there should be constant repetition and practice. The teacher's methods and the textbook program should agree and coincide.

Ratke's teacher-centred education

Fifth, there should be no compulsion. A teacher should not be a taskmaster. To strike a pupil was contrary to nature and did not help him learn. A pupil should be

brought to love his teacher, not hate him. On the other hand, all work was the teacher's responsibility. The pupil should listen and sit still. More generally, all children, without exception, should go to school, and no lessons should be canceled for any reason. There is, of course, a certain paradox in Ratke's views: there was to be no compulsion, and yet pupils were to remain disciplined and were not permitted to work independently.

As for curricula, Ratke suggested reading and writing in the native tongue, singing, basic mathematics, grammar, and, in the higher classes, Latin and Greek. The sciences had not yet appeared in his timetable. His demand that, above all, young people should be given instruction in the affairs of God is typical of the combination of rationalistic and religious education in the 17th century.

The pedagogy of Comenius. Comenius (1592–1670) was, even more than Ratke, a leading intellect of European educational theory in the 17th century. Born in Moravia, he was forced by the circumstances of the Thirty Years' War to wander constantly from place to place—Germany, Poland, England, Sweden, Hungary, Transylvania, and Holland—and was deprived of his wife, children, and property. He himself said, "My life was one long journey. I never had a homeland."

As a onetime bishop of the Bohemian Brethren, he sought to live according to their motto, "Away from the world towards Heaven." To prepare for the hereafter, Comenius taught, one should "live rightly"—that is, seek learned piety by living one's life according to correct principles of science and morality. Comenius' philosophy was both humanitarian and universalistic. In his *Pampaedia* ("Universal Education," discovered in 1935), he argued that "the whole of the human race may become educated, men of all ages, all conditions, both sexes and all nations." His aim was *pansophia* (universal wisdom), which meant that "all men should be educated to full humanity"—to rationality, morality, and happiness.

The curriculum of Comenius

Comenius realized that, to achieve *pansophia* by universal education, radical reforms in pedagogy and in the organization of schools were required, and he devised an all-embracing school system to meet this need. During infancy (up to six years of age), the child in the "mother school," or family grouping, would develop basic physical faculties. During the following period (seven to 12), the child would go to the "vernacular school," which was divided into six classes according to age and could be found in every town. The prime aim of these schools would be to develop the child's imagination and memory through such subjects as religion, ethics, diction, reading, writing, basic mathematics, music, domestic economy, civics, history, geography, and handicraft. This vernacular school formed the final stage of education for technical vocations. After this school would come the grammar school (or Latin school), which the pupils would attend during their youth (13–18) and which would exist in every town of every district. Through progressive courses in language and the exact sciences, the young people would be brought to a deeper understanding of things. Finally, the university (19–24) would be a continuation of this school. Every province ought to have one such university, whose central task would be the formation of willpower and powers of judgment and categorization. Over and above this four-tier school system Comenius also envisaged a "college of light," a kind of academy of the sciences for the centralized pooling of all learning. It is important to note, in this regard, that it was Comenius' stay in England (1641–42) that initiated discussions leading to the founding of the Royal Society (incorporated 1662). Furthermore, the German philosopher Leibniz, influenced by Comenius, founded the Berlin Academy, and similar societies sprouted elsewhere.

The Great Didactic (1657) sets forth Comenius' methodology—one for the arts, another for the sciences. Comenius believed that everything should be presented to the child's senses—and to as many senses as possible, using pictures, models, workshops, music, and other "objective" means. With proper presentation, the mind of the child could become a "psychological" counterpart of the world of nature. The mind can take in what is in nature if the method of teaching most akin to nature is used. For the upper age levels, he recommended that language study and other studies be integrated, and indeed he employed this scheme in his *Gate of Tongues Unlocked* (1631), a book of Latin and sciences arranged by subjects, which revolutionized Latin teaching and was translated into 16 languages. *The Visible World in Pictures* (1658), which remained popular in Europe for two centuries, attempted to dramatize Latin through pictures illustrating Latin sentences, accompanied by one or two vernacular translations.

Systematizing education

The schools of Gotha. The zeal for reform on the part of such educators as Ratke and Comenius, on the one hand, and the interests of the ruling classes, on the other, led in the years after about 1650 to the publication of school regulations, free of church regulations. The circumstances in the central German principality of Gotha were typical. The duke, Ernst the Pious, commissioned the rector Andreas Reyher to compile a system of school regulations, which appeared in 1642 and is known historically as the *Gothaer Schulmethodus.* This was the first independent civil system of school regulations in Germany and was strongly influenced by Ratke. The most important points of these regulations were compulsory schooling from the age of five; division of the school into lower, middle, and higher classes; extension of the usual subjects (reading, writing, basic arithmetic, singing, and religion) to various other fields (natural history, local history, civics, and domestic economy); the introduction of textbooks (for reading and basic arithmetic), notably the first textbook of exact sciences for elementary schools, Reyher's own *Kurzer Unterricht von natürlichen Dingen* (1657; "Short Course on Natural Things"); and methodical instruction that, above all, emphasized the clarity of the lesson and the activity of the pupils.

French theories and practices. In the second half of the 17th century Germany suffered from the aftereffects of the Thirty Years' War, whereas France under Louis XIV reached the zenith of political and military power. France's leadership was also demonstrated in the cultural field—including education. Some of the most important developments in France included the promotion of courtly education and the involvement of religious orders and congregations in the education of the poor.

Views of Montaigne

Courtly education. The rationalistic ideal of French courtly education can be seen foreshadowed in Montaigne's *Essays* (1580), in which the ideal man was described as having a natural, sensible way of life not deeply affected by the perplexities of the time but admitting of pleasure. He had a "correct" attitude toward the world and people, a certain spiritual freedom, and an independent judgment—all of which, in Montaigne's view, were more important than being steeped in knowledge. "As lamps are extinguished from too much oil, so is the mind from too much studying." Montaigne came from a merchant family that aspired to nobility, and thus there is a certain fashionable elitism in his views; he held, among other things, that courtly education succeeds best when the pupil studies under a private tutor.

This ideal, rather unlike the ideal of the learned and humanistic Renaissance man, became important in 17th-century France, especially after mid-century and the rise of the court of Louis XIV. The education of the would-be versatile and worldly-wise gentleman was furthered not only by the continuation of the institution of private tutoring but also by the establishment of schools and academies for chevaliers and nobles, in which the emphasis was on such subjects as deportment, modern languages, fencing, and riding. It was most emphatically an example of class education, designed for the nobility and higher military and not for any commoners.

The teaching congregations. In the countries, such as France, that remained Catholic, the Roman church retained control of education, and indeed, as monarchy became more absolute, so largely did the authority of the church in matters of education. In France, practically all schools and universities were controlled by so-called teaching congregations or societies, the most famous and powerful of which during the first half of the 17th century was the Society of Jesus. By mid-century the Jesuits

had 14,000 pupils under instruction in Paris alone; and their colleges (not including universities) all over the land numbered 612.

Jesuit education

It was their successful teaching and comparatively mild discipline that caused the Jesuit schools to attract thousands of pupils. "They are so good," said Bacon of the Jesuit teachers in his *Advancement of Learning,* "that I wish they were on our side." The curriculum was purely classical, but importance was attached to spacious, well-adapted buildings and amenities designed to make school life interesting. In general, however, the religious and international conflicts did great harm to education, which suffered much because those kings and religious factions that gained power in France (as elsewhere) used the schools to propagate their cause, discarding teachers not of the approved persuasion. Moreover, the schools continued largely to ignore the new directions of men's minds; in the universities staffed by Jesuit fathers, medieval Scholasticism, though purged of the formalistic excesses that had degraded it, was fully restored. Schools and universities declined for the most part to contemplate any enlargement of the frontiers of knowledge and were too often deeply involved in the religious conflicts of the time. The University of Paris in particular remained distracted throughout the 17th century by theological dissensions—in at least one instance as a result of the rivalry that ensued after the Jesuits had effected a footing at Clermont College.

Aside from the Jesuits, the most important teaching congregations in France were the Bérullian Oratory, or Oratorians, and the Jansenists of Port-Royal. The former, founded in 1611 and soon to open a number of schools and seminaries for young nobles, was composed of priests—but priests more liberal and rationalist than was common for the times. They offered instruction not only in the humanities but also in history, mathematics, the natural sciences, and such genteel accomplishments as dancing and music and, though continuing to use Latin in instruction, promoted also the use of the vernacular French in the initial years of their curriculum. They tended indeed to be drawn to the ideas of Descartes, to a faith based on reason. When in 1764 the Jesuits were banned from France, their teaching positions were largely assumed by Oratorians.

The Jansenists

More famous than the schools of the Oratorians, though enjoying a briefer career, were the Little Schools of Port-Royal. Their founder was Jean Duvergier de Hauranne, better known as the abbot of Saint-Cyran, who was one of France's chief advocates of Jansenism, a movement opposed to Jesuitry and Scholasticism and favouring bold reforms of the church and a turn to a certain Pietism. About 1635 Saint-Cyran, with the help of some wealthy, influential Parisians, succeeded in gaining control of the convent of Port-Royal, near Versailles. There the Jansenist group began about 1637 to educate a few boys, and by 1646 it had established the Little Schools of Port-Royal in Paris itself. Their curriculum was similar to that of the Oratorians, though excluding dancing, and was celebrated for its excellence in French language and logic and in foreign languages. Influenced by Descartes's rationalistic philosophy, the Jansenists theorized that learning has a "natural" order and should begin with what is familiar to the child: thus, a phonetic system of teaching reading was used; all instruction was in French, not Latin; student compositions were directed toward topics drawing on one's own experiences or toward subjects in one's current reading. Involved in political struggles with the Jesuits, who were still influential at court, the Jansenists were fated to have all their schools closed down by 1660, but their theories and practices were widely adopted and became extremely influential.

Female education. During the century, the education of girls was not entirely neglected, and France was notable for its efforts. Mme de Maintenon, for instance, had been a pupil of the Ursuline nuns in Paris and then a governess at the court of Louis XIV before she was wedded to the king in 1684. From her royal vantage point, she took upon herself the founding of a school in 1686 at Saint-Cyr near Versailles—a higher school principally for orphan girls descended from noble families. Besides such basic subjects as reading and writing, the girls were prepared for their future lives as wives and mothers or as members of genteel professions. In 1692 this school was taken over by the Augustinian nuns. Another important worker in the field of female education was St. Jane Frances de Chantal, who, together with her father confessor, St. Francis de Sales, founded in 1610 the order of the Visitandines, a group dedicated to charitable work and the religious education of women.

Views of Fénelon

François de Salignac de La Mothe-Fénelon, archbishop of Cambrai and noted theologian and writer, is especially known for his views on the education of girls. In his *Traité de l'éducation des filles* (1687; "Treatise on the Education of Girls") he remarked on the importance of women in improving the morals of society and went on to express his thoughts about girls' education. Because girls, he believed, are meant to fulfill roles as housewives and mothers, they should pursue religious and moral education rather than scholarly learning. They should learn reading and writing, basic mathematics, history, music, needlework, Latin (because it is the church language), but no modern languages, since they tend to moral corruption. Education, he maintained, should make the lady of the house both Christian and accomplished, neither ignorant nor précieuse.

English theories and practices. The 17th century in England (up to the Glorious Revolution of 1688–89) was one of argument over religious and political settlements bequeathed by Queen Elizabeth I; the period was one characterized by the confrontation of two different world-views—on one side the royalist Cavaliers and on the other side the Puritans. The division was reflected in education.

The Puritan Reformers. In the Anglo-American world the Reformation came about in the form of Calvinism—"Puritan" being the derisory name for strict Calvinists. Their ideals were sober, practical behaviour, careful management, thrift, asceticism, and the rejection of hedonistic pleasures of life. Many of the educationists who sought this Puritan ideal were followers of the reform plans of Comenius. Samuel Hartlib, a Polish merchant residing in England who was friend, publisher, and patron of Comenius, tried to interest Parliament in the idea of popular education; his treatise *London's Charity Enlarged* (1650) proposed that a grant be made for the education of poor children, all in the interest of general social betterment. The Committee for Advancement of Learning, which he founded in 1653, was the impulse and model for later educational associations. In general, his ideas for reform included the introduction of agricultural schools and the state organization of the educational system, as well as the establishment of general elementary education.

The name of John Dury stands close to those of Comenius and Hartlib. In 1651 appeared his book *The Reformed School,* in which he proposed teaching societies in England much like the teaching congregations in France. Indeed, he was particularly insistent that control of education be in the hands not of a regimentizing state but of free educational organizations. He was also concerned about teaching youth the useful arts and sciences so that they might "become profitable instruments of the Commonwealth." From him, too, stemmed the draft of a nursery school; thus, he can be regarded as the first representative of infant teaching in England.

The humanism of John Milton

The most renowned of the Puritan intellectuals, John Milton, was more concerned with the education of "our nobler and our gentler youth" than with the education of common boys. *Of Education* (1644), written at the request of Hartlib, was one of the last in the long line of European expositions of Renaissance humanism. Milton's aim was the traditional aim, the molding of boys into enlightened, cultivated, responsible citizens and leaders. His proposed academy, which would take the place of both secondary school and college, was to concentrate on instruction in the ancient classics, with due subordination to the Bible and Christian teaching. Milton also emphasized the sciences, and physical and martial exercise had a place in his curriculum as well.

Royalist education. Frequently opposed to Puritanism on educational as well as political grounds were the royalists and supporters of the nobility. In education, their

views went back to Elyot and Ascham in the 16th century, who had written so persuasively about the education of gentlemen in the tradition of the so-called courtesy books. Influenced by these few English forerunners and also by Montaigne were James Cleland (*The Institution of a Young Nobleman,* 1607) and Henry Peacham (*The Compleat Gentlemen,* 1622). In the view of the latter, an extreme royalist, "Fashioning him [the pupil] absolute in the most necessary and commendable Qualities concerning Minde and Body to country's glory" was the overriding aim of education; the table of contents of *The Compleat Gentlemen* exhibits the variety of interests of an ideal gentleman or noble—cosmography, geometry, poetry, music, sculpture, drawing, painting, heraldry, and so on. John Gailhard (*The Compleat Gentleman,* 1678), another writer in the same tradition, can be said to have anticipated John Locke's empiricism (see below) when he wrote that "the nature of Youth is like Wax by fire, or a smooth table upon which anything can be written."

The academies. The beginning of academies for the promotion of philosophy, arts, or sciences can be traced to the early Renaissance, particularly in Italy and France. The Platonic Academy in Florence, cited earlier in this article, was one of the most noted of speculative societies. The first scientific academies belong to the 16th century: in 1560, for instance, the Academia Secretorum Naturae ("Secret Academy of Nature") was founded in Naples; in 1575 Philip II of Spain founded in Madrid the Academy of Mathematical Sciences. Then, in 1617, the first German academy, Fruchtbringende Gesellschaft ("Productive Society"), was founded at Weimar with the expressed purposes of the purification of the language and the cultivation of literature. A number of other academies were founded throughout Europe.

The Royal Society and the Academy of Sciences

It was in the 17th century that the two preeminent scientific academies were founded. Both the English Royal Society and the French Academy of Sciences began as informal gatherings of famous men. The "invisible college" of London and Oxford had its first meetings in 1645; it was incorporated as the Royal Society in 1662. In Paris, a group of men including the philosophers Descartes and Pascal started private meetings almost at the same time. In 1666 they were invited by the economic minister Jean-Baptiste Colbert to meet in the royal library. In 1699 the society was transferred to the Louvre under the name of the Academy of Sciences. The French Academy also started as a private society of men of letters some five years before its incorporation in 1635 under the patronage of Cardinal de Richelieu. In the 18th century, the fame and achievements of these English and French academies became internationally recognized, and many other European countries started to found their own national academies.

EDUCATION IN 18TH-CENTURY EUROPE

In the 18th century the theories and systems of education were influenced by various philosophical and social trends. Among these were realism, which had its origins in Ratke and Comenius, among others, and also Pietism, which derived principally from Philipp Jakob Spener and August Hermann Francke in the late 17th and early 18th centuries (see below). Another trend was the far-reaching rationalistic and humanitarian movement of the Enlightenment, best seen in the pedagogical views of Locke, in the upsurge of philanthropy, and in Denis Diderot's *Encyclopédie,* a comprehensive system of human knowledge in 28 volumes (1751–72). Also important was naturalism, of which Jean-Jacques Rousseau can be regarded as the main representative.

Locke's theory of knowledge

Education during the Enlightenment. *John Locke's empiricism and education as conduct.* The writings of the late 17th-century empiricist John Locke on philosophy, government, and education were especially influential during the Enlightenment. For education, Locke is significant both for his general theory of knowledge and for his ideas on the education of youth. Locke's empiricism, expressed in his notion that ideas originate in experience, was used to attack the doctrine that principles of reason are innate in the human mind. In *An Essay Concerning Human Understanding* (1690) Locke argued that ideas come from two "fountains" of experience: sensation, through which the senses convey perceptions into the mind, and reflection, whereby the mind works with the perceptions, forming ideas. Locke through of the mind as a "blank tablet" prior to experience, but he did not claim that all minds are equal. He insisted, in *Some Thoughts Concerning Education* (1693), that some minds have a greater intellectual potential than others.

For education, Locke's empiricism meant that learning comes about only through experience. Education, which Locke felt should address both character and intellect, is therefore best achieved by providing the pupil with examples of proper thought and behaviour, by training the child to witness and share in the habits of virtue that are part of the conventional wisdom of the rational and practical man. Virtue should be cultivated through proper upbringing, preparatory to "studies" in the strict sense. The child first learns to do through activity and, later, comes to understand what has been done. The intimacy between conduct and thinking is best illustrated in the title of Locke's *Of the Conduct of the Understanding,* written as an appendix to his *Essay.* There it is clear that understanding comes only with careful cultivation and practice; this means that understanding not only involves conduct but is itself a kind of conduct. If the child and the tutor share a kind of conduct, then the child will have learned the habits of character and mind that are necessary for education to continue.

Vico's emphasis on imagination

Giambattista Vico, critic of Cartesianism. Like Locke, the Italian philosopher Giambattista Vico believed that human beings are not innately rational; he argued, however, that understanding results not through sense perception but through imaginative reconstruction. Although Vico's ideas were not widely known in the 18th century, the importance of his work for the history of philosophy and education has been increasingly recognized since the late 1960s. Vico was professor of rhetoric at the University of Naples from 1699 to 1741. His best-known work is *New Science* (1725), in which he advanced the idea that human beings in their origins are not rational, like philosophers, but imaginative, like poets. The relation between imagination and reason in *New Science* is suggestive for educational theory: civilized human beings are rational, yet they came to be that way without knowing what they were doing; the first humans created institutions literally without reason, as poets do who follow their imagination rather than their reason. Only later, after they have become rational, can human beings understand what they are and what they have made. Vico's idea that early humans were nonrational and childlike prefigured Rousseau's primitivism and his conception of human development (see below); and the importance Vico accorded to imagination foreshadowed the place that feeling was to have in 19th-century Romantic thought.

De Nostri Temporis Studiorum Ratione (1709; "On the Study Methods of Our Time") defended the humanistic program of studies against what Vico took to be an encroachment by the rationalistic system of Descartes on the educational methods proper for youth. Vico asserted that the influential Cartesian treatise *The Port-Royal Logic,* by the Jansenists Antoine Arnauld and Pierre Nicole, inverted the natural course by which children learn by insisting on a training in logic at the beginning of the educational process. He argued, instead, that young people need to have their mental powers developed and nourished by promoting their memories through the study of languages and enhancing their imaginations through reading poets, historians, and orators. Young minds first need the kind of reasoning that common sense provides. Common sense, acquired through the experience of poets, orators, and people of prudence, teaches the young the importance of working with probabilities prior to an education in logic. To train youth first in logic in the absence of common sense is to teach them to make judgments before they have the knowledge necessary to do so. Vico's aim was to emphasize the importance of practical judgment in education, an echo of the ideals of Locke and a prefiguring of Rousseau and the 19th-century reformer Johann Heinrich

Pestalozzi. Outside of Italy, among those who were most influenced by *New Science* were Joseph de Maistre in the late 18th century and Victor Cousin and Jules Michelet in the 19th century.

The condition of the schools and universities. The school system became more and more in the 18th century an ordered concern of the state. Exponents of enlightened absolutism, as well as parliamentarians, recognized that the subject was of more use to the state if he had a school education. Ideally, there was to be compulsory schooling everywhere, but of course in practice the ideal was scarcely reached anywhere. The state also recognized that worthwhile school instruction depended on the standard of education of teachers: thus, the first teachers' colleges were established. But admittedly the standard of education of teachers was fairly poor. The teaching profession still did not provide a living wage, for which reason can be read from a regulation of 1736:

> If the teacher is a workman he can already support himself; if he is not, then he is hereby allowed to go to work for daily wages for 6 weeks at harvest-time (*Principia regulativa,* clause 10).

Ever since the 16th century the universities had suffered a decline, mainly as a result of religious wars. Progress in the exact sciences was accomplished under government support in the academies of science, not in the universities, which became more and more training institutions for higher civil servants. There was, however, a notable change for the better, at least in Germany.

Halle, the first modern university

The year 1694 saw the foundation of the University of Halle, which has been described as the first real modern university. It originated in a *Ritterschule,* or "knight's school," imitative of the schools for chevaliers in France, and in 1694 the Holy Roman emperor Leopold I granted it a charter. The primary object in founding a university in Halle was to create a centre for the Lutheran party; but its character, under the influence of its two most notable teachers, the philosophers Christian Thomasius and Francke, soon expanded beyond the limits of this conception. Thomasius was the first to set the example—soon after followed by all the universities of Germany—of lecturing in the vernacular instead of the customary Latin; this was a declaration of war against Scholasticism. Francke, as the founder of the Pietistic school, exercised great influence. Throughout the whole of the 18th century Halle was the leader of academic thought and advanced theology in Protestant Germany, although sharing that leadership, after the middle of the century, with the University of Göttingen (founded 1737). With Göttingen, another important contribution was made by the revival of classical studies and the creation of a faculty of philosophy distinct from that of theology. This was designed not only to advance scholarship but also to train teachers. Halle itself established the first chair of educational theory.

The background and influence of Pietism. The dispute over the correct religious dogma, fought for almost 200 years with the utmost strength, controversy, and academic subtlety and reaching its terrible culmination in the Thirty Years' War, led to a certain ill feeling against dogmatically sanctioned religious revelation. There was a widespread trend toward secularization. Everywhere, there was a clear tendency to free belief from dogmatic quarrels. The search for a new belief took generally two different paths. One wanted to base belief in man's reason; the other wanted a godliness of the heart. For one line of thought, belief was a postulate of omnipotent human reason; for the other, man, corrupted by original sin, was to be saved only by simple belief in God's grace. The one path turned to the religious understanding of the Enlightenment; the other followed the subjective, mystical, zealous devoutness of Pietism. Such a movement away from the institutionalized church, away from the established church, and toward an intensified faith was evident in France within Roman Catholicism in the form of Jansenism and Quietism. In England it was clearly evident in certain forms of Puritanism and in Independent movements and Quakerism. In Germany it was evident in Pietism.

Rationalistic versus devotional experience

Pietism was a Protestant movement of renewed faith that became popular from about 1675 to 1740, though it remained residually influential even into the 19th century. Its spiritual centres were in Württemberg, among the Moravian Brethren, and above all in Halle. Pietism was principally opposed to dogmatic Protestant orthodoxy, which usually included impatience and polemics against other beliefs. Pietism, on the contrary, stood for the renewal of importance of the individual prayer and for humility. The experiences of belief were to be based less in the acceptance of fixed conditions of belief and more in a mystical, personal submersion in feelings. According to standard Protestant theory, salvation could be hoped for only by the suppression of the corrupted individuality and by waiting for the grace of God to show one the way. From this came the Pietists' inclination to turn away from the world with its temptations (*e.g.,* the theatre, dancing, games, and other enjoyments). The uneasiness that they felt toward church institutionalization led to their splitting into numerous separatist groups; their subjective certainty about their belief led to a certain arrogance; and finally their seclusion led often to a joyless and moralizing way of life.

Although the founder of German Pietism is considered to be Spener, who established several private devotional gatherings (*collegia pietatis*) for Bible study in Frankfurt am Main and elsewhere, he was important for education only in the sense that he fashioned a spirit or concept in which education could be conducted—a concept that would subordinate all education to a simple Christian faith. This concept was realized mainly by his follower Francke.

August Hermann Francke. Francke, after service as a grammar-school teacher and priest in Leipzig, Lübeck, Hamburg, and Erfurt, was, through Spener's recommendation, given a post at the University of Halle in 1691, at the same time assuming the post of parish priest nearby. Motivated by the sad conditions of neglect in his parish, he quickly devoted himself to practical pastoral duties. In 1695 he instituted a vernacular school for the poor, popularly called the "ragged school," whose purpose was that the children should be led to a living knowledge of God and Christ and to a rightly accomplished Christianity. Through his activity and eloquence Francke won several charitable patrons for his school, and the institution quickly expanded. After the school for the poor came the establishment of an elementary school for children of fee-paying burghers, then an orphanage, and lastly a *Pädagogium,* or boarding school, for the sons of nobility. Because Francke felt a lack of suitable teachers for his schools, he subsequently established two teachers' seminaries, *seminarium praeceptorum* and *seminarium selectum* (for teachers in higher schools). In 1697 there followed a Latin grammar school and in 1698, even if short-lived, a *gynaeceum,* a school for the daughters of nobility. To the whole complex of Halle's institutions (known collectively as the Halle Foundation) there also belonged a bookshop with a publishing house and press, a very profitable chemistry laboratory, as well as four agricultural properties, a Bible institution, and an office for sending evangelical missions abroad. These institutions flourished, and about 1750 they were more and more brought under the control of the state.

The schools of Halle

Francke's main concern was ministerial work in the spirit of Pietism and not systematic educational theorizing. His educational aims were religious and at the same time practical. He himself paraphrased it as "true godliness and Christian wisdom"—true godliness meaning a pious, moral, devout life, and Christian wisdom referring to an ability to work hard according to the Protestant ethic. Francke's style of education went along with this aim: the corrupted willfulness of man must be broken, not through severe punishment but through "loving reproaches," a close supervision of the pupils, and a schooled and regimented care of the spirit. Games and childlike exuberance have no place in the system; thus, education had a joyless and moralizing effect.

Strictness and realism in Pietistic schools

The harsh demands and regimentation are shown, for instance, in the daily timetable and the syllabus. The children arose at 5:00 AM; there was almost continuous instruction with frequent Bible reading and religious

lessons until 7:00 in the evening. The grammar school had lessons in reading, writing, basic mathematics, catechism, the Holy Scriptures, Latin, Greek, Hebrew, optionally another Oriental language, geography, history, mathematics (including astronomy and geometry), botany, zoology, mineralogy, anatomy, and theology, as well as lathework, glass polishing, field trips to observe trades, factory work, horticulture, and so on. These latter subjects were counted as "recreation." The pansophic idea of Comenius was being followed here, in the sense that there was to be an all-encompassing education. It is worth noting that Francke was actually trying to inject realism into education—promoting, as he did, scientific subjects, lessons in manual skills, planned field trips, and even the reading of newspapers in the classroom.

Johann Julius Hecker. Julius Hecker came to Halle shortly before Francke's death in 1727 and became a teacher in the *Pädagogium.* In 1739 he was summoned by Frederick I of Prussia to Berlin, where he established a six-year *Realschule,* or "realist school," designed to prepare youth for the Pietistic and Calvinistic ideal of hard work and, especially, for the new technical and industrial age that was already dawning in countries such as England and France. Godliness was to be combined with a realistic and practical way of life. As early as 1699 Francke had conceived the idea of a school for children who were not meant for scholarship but who could serve usefully in commercial pursuits or administration; and in 1739 one of his teachers, Christoph Semler, published a pamphlet proposing such a "mathematical and mechanical *Realschule.*" It was Hecker's fortune to put these plans into realization. His school included, among other things, classes for architecture, building, manufacturing, commerce, and trade. Both the exact sciences and manual skills were in the curriculum. A room for natural-history specimens, geographic maps, and realia was set aside for the illustration of lessons. Schools like Hecker's were gradually opened in other cities. In the 19th century courses were extended to nine years, and such an institution was renamed *Oberrealschule,* or "higher realist school"; henceforth it was one of the main types of German secondary education. Hecker also compiled the general school regulations (1763) that formed the main outlines of the Prussian school system.

Real-schule, or "realist school"

The background and influence of naturalism. Pietists emphasized Christian devotion and diligence as paths to the good life; Enlightenment thinkers focused on reason and clear thinking as the sensible way to happiness. Rousseau and his followers were intrigued by a third and more elusive ideal: naturalism. Rousseau, in his *A Discourse on Inequality,* an account of the historical development of the human race, distinguished between "natural man" (man as formed by nature) and "social man" (man as shaped by society). He argued that good education should develop the nature of man. Yet Rousseau found that mankind has not one nature but several: man originally lived in a "pure state of nature" but was altered by changes beyond control and took on a different nature; this nature, in turn, was changed as man became social. The creation of the arts and sciences caused man to become "less pure," more artificial, and egoistic, and man's egoistic nature prevents him from regaining the simplicity of original human nature. Rousseau is pessimistic, almost fatalistic, about changing the nature of modern man.

Émile, his major work on education, describes an attempt to educate a simple and pure natural child for life in a world from which social man is estranged. Émile is removed from man's society to a little society inhabited only by the child and his tutor. Social elements enter the little society through the tutor's knowledge when the tutor thinks Émile can learn something from them. Rousseau's aim throughout is to show how a natural education, unlike the artificial and formal education of society, enables Émile to become social, moral, and rational while remaining true to his original nature. Because Émile is educated to be a man, not a priest, a soldier, or an attorney, he will be able to do what is needed in any situation.

Rousseau's educational ideas in *Émile*

The first book of *Émile* describes the period from birth to learning to speak. The most important thing for the healthy and natural development of the child at this age is that he learn to use his physical powers, especially the sense organs. The teacher must pay special attention to distinguishing between the real needs of the child and his whims and fancies. The second book covers the time from the child's learning to speak to the age of 12. Games and other forms of amusement should be allowed at this age, and the child should by no means be overtaxed by scholarly instruction at too early an age. The child Émile is to learn through experience, not through words; he is to bow not to the commands of man but to necessities. The third book is devoted to the ages from 12 to 15. This is the time of learning, not from books of course but from the "book of the world." Émile must gain knowledge in concrete situations provided by his tutor. He learns a trade, among other things. He studies science, not by receiving instruction in its facts but by making the instruments necessary to solve scientific problems of a practical sort. Not until the age of 15, described in the fourth book, does Émile study the history of man and social experience and thus encounter the world of morals and conscience. During this stage Émile is on the threshold of social maturity and the "age of reason." Finally, he marries and, his education over, tells his tutor that the only chains he knows are those of necessity and that he will thus be free anywhere on earth.

The final book describes the education of Sophie, the girl who marries Émile. In Rousseau's view, the education of girls was to be similar with regard to naturalness, but it differed because of sexual differences. A girl cannot be educated to be a man. According to Rousseau, a woman should be the centre of the family, a housewife, and a mother. She should strive to please her husband, concern herself more than he with having a good reputation, and be satisfied with a simple religion of the emotions. Because her intellectual education is not of the essence, "her studies must all be on the practical side."

At the close of *Émile,* Rousseau cannot assure the reader that Émile and Sophie will be happy when they live apart from the tutor; the outcome of his experiment is in doubt, even in his own mind. Even so, probably no other writer in modern times has inspired as many generations as did Rousseau. His dramatic portrayal of the estrangement of natural man from society jolted and influenced such contemporary thinkers as Immanuel Kant and continues to intrigue philosophers and social scientists. His idea that teachers must see things as children do inspired Pestalozzi and has endured as a much-imitated ideal. Finally, his emphasis on understanding the child's nature had a profound influence by creating interest in the study of child development, inspiring the work of such psychologists as G. Stanley Hall and Jean Piaget.

The Sensationists. A group of French writers contemporary with Rousseau and paralleling in some ways the thought of both Rousseau and Locke are known as the Sensationists, or, sometimes, the Sensationist psychologists. One of them was Étienne Bonnot de Condillac, who, along with Voltaire, may be said to have introduced Locke's philosophy to France and established it there.

Views of Condillac

In the *Treatise on Sensations* (1754) Condillac imagined a statue organized inwardly like a man but animated by a soul that had never received an idea or a sense impression. He then unlocked its senses one by one. The statue's power of attention came into existence through its consciousness of sensory experience; next, it developed memory, the lingering of sensory experience; with memory, it was able to compare experiences, and so judgment arose. Each development made the statue more human and dramatized Condillac's idea that man is nothing but what he acquires, beginning with sensory experience. Condillac rejected the notion of innate ideas, arguing instead that all faculties are acquired. The educational significance of this idea is found in Condillac's *An Essay on the Origin of Human Knowledge* (1746), where he writes of a "method of analysis," by which the mind observes "in a successive order the qualities of an object, so as to give them in the mind the simultaneous order in which they exist." The idea that there is a natural order which the mind can learn to follow demonstrates Condillac's naturalism along with

his sensationism. Condillac does not begin his work *Logic* (1780) with axioms or principles; rather, he writes, "we shall begin by observing the lessons which nature gives us." He explains that the method of analysis is akin to the way that children learn when they acquire knowledge without the help of adults. Nature will tell man how to know, if he will but listen as children "naturally" do. Thus the way in which ideas and faculties originate is the way of logic, and to communicate a truth is to follow the order in which ideas come from the senses.

Claude-Adrien Helvétius, a countryman of Condillac's who professed much the same philosophy, was perhaps even more insistent that all human beings lack any intellectual endowment at birth and that despite differing physical constitutions each person has the potential for identical passions and ideas. What makes people different in later life are differing experiences. Hypothetically, two men brought up with the same chance experiences and education would be exactly the same. From this it followed, in education, that the teacher must attempt to control the environment of the child and guide his instruction step by step. Helvétius was, perhaps, unique in joining such a strong belief in intellectual equalitarianism with the possibility of a controlling environmentalism.

The Rousseauists. Rousseau left behind no disciples in the sense of a definite academic community, but hardly a single theorist of the late 18th century or afterward could avoid the influence of his ideas. One of those influenced was the German Johann Bernhard Basedow, who agreed with Rousseau's enthusiasm for nature, with his emphasis on manual and practical skills, and with his demand for practical experience rather than empty verbalism. The teacher, in Basedow's view, should take pains over the clearness of the lesson and make use of the enjoyment of games: "It is possible to arrange nearly all playing of children in an instructive way." In another respect, however, the contrast between Rousseau and Basedow could not be sharper; Basedow tended to force premature learning and overload a child's capabilities. A foreign language, for instance, was to be learned in six months. He promoted, in general, a pedagogic hothouse atmosphere. Basedow was perhaps influenced by his seven-year-old daughter, who was put forward as a wonder child with extraordinary knowledge. He established an experimental school called a *Philanthropinum,* in Dessau, which lasted from 1774 to 1793.

Kant on pedagogy

Kant referred to Rousseau's influence on him. He dealt specifically with pedagogy only within a lecture he gave as holder of the chair of philosophy in Königsberg; the main features of the lecture were collected in a short work, *Über Pädagogik* (1803; "On Pedagogy"). In it he asserted, "A man can only become a man through education. He is nothing more than what education makes him." Education should discipline man and make him cultured and moral; its aim is ultimately the creation of a happier mankind. In general, Kant agreed with Rousseau's education according to nature; but, from his ethical posture, he insisted that restraints be put on the child's passionate impulses and that the child even be taught specific maxims of conduct. The child must learn to rule himself and come to terms with the twin necessities of liberty and constraint, the product of which is true freedom.

> Children should be educated, not with reference to the present conditions of things, but rather with regard to a possibly improved state of the human race—that is, according to the ideal of humanity and its entire destiny. (From *Über Pädagogik.*)

The influence of nationalism. The Enlightenment was cosmopolitan in its effort to spread the light of reason, but from the very beginning of the age there were nationalistic tendencies to be seen in varying shades. Although Rousseau himself was generally concerned with universal man in such works as *The Social Contract* and *Émile,* his *The Government of Poland* (1782) did lay out a proposal for an education with a national basis, and generally his ideas influenced the nationalistic generation of the French Revolution of 1789.

National views of the Philosophes

France. The real starting point generally of national pedagogic movements was in France. It perhaps began with the Philosophes, the rationalists and liberals such as Voltaire and Diderot, who emphasized the development of the individual through state education, not as a means, of course, of adjusting to the state and its current government but as a means of creating critical, detached, responsible citizens. The Marquis de Condorcet was closely connected with this line of thought. For him man was by nature good and capable of never-ending perfection, and the goal of education should be the "general, gradually increasing perfection of man." He drafted a democratic and liberal but at the same time somewhat socialist concept of school policy: there should be a uniform structure of public education and equal chances for all; ability and attainment should be the only standards for selection and careers; and private interests should be prevented from having influence in the educational system. An educational concept so rationalistic in its aims and with such a democratic and liberal structure cannot be narrowly nationalistic; it is cosmopolitan. But Condorcet was nationalistic insofar as he wanted "to show the world at last a nation in which freedom and equality for all was an actuality." He was, in fact, a strong supporter of the Revolution.

Many of the Rousseauists were nationalistic in a somewhat different way. They believed in a kind of "moral patriotism." They distrusted state-controlled nationalism and favoured instead a virtuous, patriotic citizen who experienced spontaneous feelings for his nation. Proper development in the family setting and in school would lead to the mastery of everyday situations and would naturally lay the foundations for this true nationalism.

Some of the French revolutionists, particularly Jacobins such as Robespierre and Saint-Just who were associated with the period of the Terror (1793–94), were concerned with an education for the revolutionary state, an education marked by an enmity toward the idea of scholarship for its own sake and by state control, collectivism, the stressing of absolute equality, and the complete integration of all. What is good is decided by the collective "people." Thus, it could be said that the Jacobins favoured a complete politicalization of educational practice and theory.

Benevolent despotism and education

National education under enlightened rulers. The absolutism of the 18th century has often been called "benevolent despotism," referring to the rule of such monarchs as Frederick II the Great of Prussia, Peter I the Great and Catherine II the Great of Russia, Maria Theresa and Joseph II of Austria, and lesser figures who were presumably sufficiently touched by the ideas of the Enlightenment to pursue social reforms. Their reforms were limited, however, and usually did not include anything likely to upset their sovereignty. Thus, they were often willing to improve education for middle-class persons useful in civil service and other areas of state administration, but they were often chary of educating the poor. That risked upsetting the social order.

Frederick the Great, however, issued general school regulations (1763) establishing compulsory schooling for boys and girls from five to 13 or 14 years of age. His minister Freiherr von Zedlitz founded a chair of pedagogy at Halle (1779) and generally planned for the improved education of teachers; he supported the founding of new schools and the centralization of school administration under an *Oberschulkollegium,* or national board of education (1787); and one of his colleagues, Friedrich Gedike, was instrumental in introducing the school-leaving examination for university entrance, the *Abitur,* which still exists.

The guarded though increasingly liberal attempt by benevolent despots to nationalize and expand education is well illustrated by the events in Russia. Until the 18th century, schools in Russia were founded by ecclesiastical organizations (monasteries), the clergy (priests, deacons, readers), and private persons (boyars, or lower-level aristocrats). Boys were taught reading, writing, arithmetic, singing, and religion. A system of state-owned schools was started by Peter the Great as a state organization for purposes of administration and for the development of mining and industry. Peter did not intend to promote the Orthodox faith or formal classical learning, whether Greek, Latin, or Slavonic, or universal education. He created mathematical, navigation, artillery, and engineering schools for utilitarian purposes. In 1725 an Academy of

Sciences with a university and a *gimnaziya* (secondary school) was founded at St. Petersburg. The utilitarian, secular, and scientific characteristics of Peter's schools became the dominant features of Russian education, but, as a result of the many changes of policy after Peter's death in 1725, a national system of education did not develop.

A second attempt at nationalizing education in Russia was made by Catherine II. After many abortive schemes, Catherine issued in 1786 a statute for schools, which can be considered the first Russian education act for the whole country. According to this act, a two-year course in minor schools was to be started in every district town and a five-year course in major schools in every provincial town. Catherinian schools were also to be utilitarian, scientific, and secular. At the end of the 18th century, 254 towns had the new schools, but 250 smaller towns and the rural districts had no schools whatever.

A third nationalizing attempt was made by Alexander I and was influenced by the disintegration of the serf system, by the development of industry and commerce, and by the ideas of the French Revolution. The new statutes (1803 and 1804) maintained the principles of utility and secular scientific instruction. The parochial schools (*prikhodskiye uchilishcha*) in the rural areas were to instruct the peasantry in reading, writing, arithmetic, and elements of agriculture; the district schools of urban areas (*uyezdnye uchilishcha*) and the provincial schools (*gimnazii*) were to give instruction in subjects necessary for civil servants—law, political economy, technology, and commerce. The system was state-controlled and free and formed a continuous ladder to the universities. Later conservative reactions, however, tended to blunt or reverse these reforms.

England. In England the development of a "national" education took a completely different course. It was influenced not by a political but by an industrial revolution. It is true that theorists such as Adam Smith, Thomas Paine, and Thomas Robert Malthus proposed state organization of elementary-schooling, but even they wanted to see limited state influence; the state could pay the musicians but not call the tune. Not until 1802 did Parliament intervene in the development of education, when the Health and Morals of Apprentices Act required employers to educate apprentices in basic mathematics, writing, and reading. For the most part this remained only a demand, since the employers were not interested in such education.

The reluctance on the part of the state induced several philanthropists to form educational societies, principally for the education of the poor. In 1796, for example, the Society for Bettering the Conditions of the Poor was founded. A further impulse for elementary education stemmed from the Sunday schools, the first of which was founded in 1780 in Gloucester; by 1785 their numbers had so increased that the Sunday School Society was founded. The lessons in such schools, however, were mainly those of Bible reading.

The monitorial, or Lancasterian, system

The educators Andrew Bell and Joseph Lancaster played a major role in progress toward an elementary-school system. They realized that the root of the problem lay in the lack of teachers and in the lack of money to hire assistants. Therefore, first Bell developed, then Lancaster modified, the so-called monitorial system (also called the Lancasterian system), whereby a teacher used his pupils to teach one another. The use of children to teach other children was not new, but Bell and especially Lancaster took the approach and developed it into a systematic plan of education. From 200 to 1,000 children were gathered in one room and seated in rows, usually of 10 pupils each. An adult teacher taught the monitors, and then each monitor taught his row of pupils the lesson in reading, writing, arithmetic, spelling, or higher subjects. Besides monitors who taught, there were, in Lancaster's system, monitors to take attendance, give examinations, issue supplies, and so on; school activity was to be directed with military precision; the emphasis was on drill and memorization. The system and the publicity connected with it expanded the efforts toward mass education, even though, pedagogically, the whole process was so routinized and formalized that opportunities for creative thinking or initiative scarcely existed. (H.-J.I./J.J.Ch.)

EUROPEAN OFFSHOOTS IN THE NEW WORLD

Spanish and Portuguese America. With the Spanish conquerors of the New World, the conquistadores, came friars and priests who immediately settled down to educate the Indians and convert them. Because there was little separation of church and state, the Roman Catholic church assumed complete control of elementary education, and the early Franciscan and Dominican friars were followed by Augustinians, Jesuits, and Mercedarians.

Church control of colonial education

The first elementary school in the New World was organized in Mexico by the Franciscan Pedro de Gante in 1523 in Texcoco, followed in 1525 by a similar school in San Francisco. Because such schools in Mexico were designed for Indian children, the monks learned the native languages and taught reading, writing, simple arithmetic, singing, and the catechism. The schools of the *hospicio* of the bishop Vasco de Quiroga in Michoacán added agriculture, trades, and crafts to their curriculum.

Mestizo children, the issue of Spanish and Indian parents, were often abandoned; thus, special institutions appeared to collect and educate them—for example, the Girls' School and the School of San Juan de Letrán, founded by Viceroy Mendoza in New Spain, and the Bethlehemite schools of Guatemala and Mexico.

In the beginning, children of Spaniards born in the colonies, called Creoles, had tutors. Eventually, schools promoted by cabildos (municipal authorities) emerged.

During the 18th century the Enlightenment came to Latin America, and with it a more secular and widespread education. Among famous projects were those of Viceroy Vertiz y Salcedo in Argentina and two model schools, free for children of the poor, by Archbishop Francos y Monroy in Guatemala. In New Spain the College of the Vizcainas (1767) became the first all-girl lay institution.

Because of the social structure, riches and administrative privilege were held by an elite, the Creoles, and secondary education was specially organized to serve them. Originally, secondary schools existed only in the monasteries, but when the Jesuits arrived in the late 1560s they founded important *colegios* (secondary institutions) to prepare students who wanted to enter the universities. There also existed a few special *colegios* for the Indian nobility, such as the outstanding Santa Cruz de Tlaltelolco (1536) in Mexico and San Andres in Quito, both founded by the Franciscans for liberal arts studies. The Jesuits also established schools for the Indians, including El Príncipe (1619) in Lima and San Borja in Cuzco. All these schools were eventually closed because of the jealousy of the Spanish bureaucracy.

Though the Dominicans and Franciscans had been pioneers in education, the Jesuits became the most important teachers. They offered an efficient education, molded to contemporary requirements, in boarding schools, where the elite of the Spaniards born in the Americas studied. When their order was expelled in 1767, education was dealt a severe blow. In Portuguese Brazil, where the expulsion edict had been issued eight years earlier and where they had been the only educators, the royal chancellor was forced to make feeble attempts toward organizing a secular education. The Spanish king Charles III also took advantage of the occasion and founded some new institutions—the Academy of San Carlos, the School of Mining in Mexico, the Royal College of San Carlos in Buenos Aires—and modernized others.

The Latin-American universities

Traditionally, Spanish universities had been organized on the model either of Paris or of Bologna. The former was a *universitas magistrorum,* governed by professors organized in faculties, whereas the latter, as a *universitas scholarium,* received its corporate authority from the student body organized into "nations" that elected leaders to whom even the professors were subject. In 1551 the Council of the Indies authorized the founding of the first American universities, one in Mexico and one in Lima; academic government was placed in the hands of a *claustro,* or faculty, composed of the rector, the teachers, and the professors. Dedicated to general studies, the universities required a papal as well as a royal authorization.

The Royal Pontifical University of Mexico was the first to open its doors, in 1553. In the Spanish colonies even-

tually 10 major and 15 minor universities came into existence. The latter were actually colleges—nine Jesuit, four Dominican, one Franciscan, and one Augustinian—which, because they were located far from the closest university (minimally 200 miles), were given special authorization to grant higher degrees. In Brazil no university existed, and Portuguese born in the colony had to go to Portugal for study.

Though in Spain itself law reigned supreme, in the Americas theology became the principal chair. Teaching was in scholastic mode: it began with the reading of a classical text; then the professor explained the thesis or proposition and offered arguments pro and contra so that a conclusion in accord with Roman Catholic dogma would result.

(J.Z.V.)

French Québec. Soon after the founding of the Québec colony in 1608, the first organized educational activity began with missionary work among the Indians, carried on mainly by members of the Récollet and Jesuit orders and, from 1639, by Ursuline nuns. The first mission "school" recorded was that of Pacifique du Plessis, established in 1616 in Trois-Rivières (Three Rivers).

Christian efforts among the Indians were only a dimension of the religious purposes that framed educational activity in Old World France. Roman Catholic social philosophy allowed no compromise in the spiritual direction of education, and both in informal socialization patterns and in what formal provisions existed the doctrine and aim of religion coincided with that of education. At the general level, education was intended to produce religious conformation in thought and behaviour; at the higher level, education was to produce a progeny of clerical leadership. The paternalistic authority of church and monarch was carried from the Old to the New World, where it perhaps became even more pervasive, due to the initial absence of alternative institutional developments. In education, the exclusive role of the state (though not insignificant) was confined to financial subsidization. Authority for the institution of education was vested in the bishop of Québec.

Most of the nonreligious functions now associated with formal education were, in the 17th and 18th centuries, carried in other institutional sectors: the family, the community, the vocation. Just as there was no sharp break between church and school in formal learning, there was an easy transition between the information and behaviour necessary for work and life as transmitted in the course of various socialization experiences. Thus, the self-sustaining and isolated life of the farmers, the wild and solitary ways of the coureurs de bois (fur traders), the miniature of European manners and customs established in the cities by the gentry—all contained within their own cycle the educative procedures for life in that society. Education as a separate institution was understandably associated with learning not related to the business of life.

The schools of New France

Institutional forms found in French colonial Québec included parish schools, girls' schools, secondary schools, and vocational schools; and literacy records indicate that the provision for education was in sum comparable to that in the Old World. Parish or common schools were irregularly provided to afford the rudiments of literacy and religion. Because of the relative sparseness of educational resources, social classes were frequently mixed in these schools. Girls' schools were established in Québec City by the Ursulines from 1642 and by the Sisters of the Congrégation de Notre Dame from 1659, with a rudimentary curriculum but including a characteristic "finishing" of social graces appropriate to the French-Canadian girl. Vocational training was probably of least concern in this early period, but specific attempts to institutionalize this educational area were begun as early as 1668 with the establishment of the School for Arts and Trades in Saint Joachim, for instruction in agriculture and certain trades.

Secondary education was offered by the Jesuits from 1636. The Jesuit college, offering early training for eventual entrance into the priesthood, was conducted along characteristically Jesuit lines: militaristic discipline in conduct, unequivocal authority in method, classical curriculum in content. The classical curriculum pattern, comprising basically Latin, Greek, mathematics, philosophy, and theology, was to be essentially preserved in the French-Canadian development of *collèges classiques* for secondary education.

In 1663 Bishop Laval established in the city of Québec the *grand séminaire* as the apex of the educational "system," as the first French-Canadian "university." Shortly thereafter, he also established the preparatory *petit séminaire*.

Following the cession of Québec to Britain in 1763, education fell prey to political and cultural disruption. Although the British military and colonial government attempted to preserve the structure of French civil and religious institutions, the cultural integrity of the system was inevitably broken. Financial grants from France for education discontinued and were not replaced by the British government; recruitment to religious orders was restricted; and educational development was obstructed by the continual association of educational plans with cultural-religious controversies. The end of the 18th century saw French-Canadian education fall backward into neglect.

(R.F.L.)

British America. *New England.* The year 1630, chronicled in New England annals as the beginning of the Great Migration, witnessed the founding there of Puritanism as the established religion. Rejecting democracy and toleration as unscriptural, the Puritans put their trust in a theocracy of the elect that brooked no divergence from Puritan orthodoxy. So close was the relation between state and church that an offense against the one was an offense against the other and, in either case, "treason to the Lord Jesus." The early Puritans also put their confidence in centralized church governance; however, geographic reality forced them to settle for a localized, congregational administration, for impossible roads made land travel over any distance onerous and even dangerous, and thus the focal point of social and political life had to be the village. Small and constricted, a place where the vital necessities, sacred and profane, were within walking range of all and where one's conduct was exposed to constant public watch, the New England village was the prime mover of communal life.

Puritan education in New England

In Puritan moral theology the young, like the old, were sinners doomed by almost insurmountable odds to perdition. To God, indeed, even infants were depraved, unregenerate, and damned. Hence, the sooner the young learned the ground rules of the good society, as revealed in the Bible, the better. The task of teaching them first befell the parents. Later, when they were old enough, the burden was conferred upon the school. The first secondary school was probably the Boston Latin School. Founded in 1635, it was modeled on the grammar schools of England, which is to say that it put an overwhelming emphasis on the ancient languages and "humane learning and good literature." By the 1640s the idea of town-supported schooling had lost its novelty.

If towns braved the first steps in education, then the Commonwealth of Massachusetts did not trail far behind. In 1642 it ordered parents and masters of apprentices to see to it that their charges were instructed in reading, religion, and the colony's principal laws. Five years later, the General Court reinforced this enactment with yet another. Aimed at the "old deluder Satan," it undertook to thwart him from keeping "men from a knowledge of the Scriptures," by requiring every township of 50 households to commission someone to teach reading and writing. The law also directed towns of 100 families to furnish instruction in Latin grammar so that youth might be "fitted for the university." Finally, the measure required teachers to be paid by "parents or masters . . . or by the inhabitants in general." The measure was given only a pallid obedience, but its assumption that the state may compel the schooling of its young and that in order to support education it may impose taxes is pertinent to subsequent times.

The founding of Harvard College

The first colonists had scarcely settled when in 1636 the General Court appropriated £400 "towards a school or college." When two years later John Harvard died and left the institution his library and some £800, the grateful founders honoured their school with his name. Designed to train youth for important Puritan places, particularly in the ministry, the college accepted only those who could

read, write, and speak Latin in prose and verse, besides knowing Greek nouns and verbs familiarly. Once admitted, the student was lodged at the college, pledged to a blameless behaviour, and put upon a prescribed four-year course of grammar, rhetoric, logic, arithmetic, geometry, astronomy, ethics, ancient history, Greek, and Hebrew. If he weathered these hazards, he was made a bachelor of arts (B.A.), and, if ambition still roweled him, he could enroll for another three years to become a master of arts (M.A.).

So things sat until the century's passing. Then, swayed by the intellectual breezes of Europe's Enlightenment, Harvard College ventured some earnest renovation. Its texts, cobwebbed with Aristotelianism, were replaced with newer ones by Locke and Sir Isaac Newton. In 1718 it added mathematics and sciences to its offerings, and 20 years later it enriched itself with a professorship of mathematics and natural philosophy. There were the usual grumblings from conservatives, and in 1701 a number of Congregational parsons, all Harvard sons, distressed by their alma mater's dalliance in newfangled ideas, inaugurated the collegiate school of Connecticut, now Yale University.

The new academies. Disdainful of the challenging intellectual values, the secondary schools continued in their classical tracks. By the 18th century, however, their tradition was playing out, especially among the rising nabobs of the marketplace. When the old schools failed to respond to their demands for an education calculated to prepare their sons for everyday living, they resorted to private schooling. From such endeavour emerged the academy. The first school of strictly native provenance, it made its advent in 1751 in Philadelphia (the Philadelphia Academy), the work in the main of Benjamin Franklin. What differentiated it from its classical antecedent was its promotion of "useful learning," to wit, the vernacular, modern languages, history, geography, chronology, navigation, mathematics, natural and applied science, and the like.

The first academies addressed themselves solely to boys, but time saw them vouchsafe instruction to girls in a "female department," which in turn gave way to the "female academy," whose curriculum reflected debates of the time about female education. Fine arts, domestic subjects, and training for occupations open to women were included, though some female educators stressed intellectual attainment rather than practical learning.

Private ventures always, academies generally were not loath to solicit outside assistance—some, indeed, as in New York, enjoyed a public subsidy. Whatever their special character, to their very end they maintained their original purpose of bringing education into closer consonance with "the great and the real business of living," as Phillips Academy of Andover, Massachusetts, phrased it when, in 1778, it held its first sessions.

Diversity of the middle colonies

The middle colonies. The religious uniformity that marked the Puritan theocracy was missing in the middle colonies. From New York through Delaware there flourished a host of sects whose scriptural interpretations were diverse—often, in fact, in collision. Nor was there even the tie of a common language, for the settlers came from many lands. Divergent in religion and language, the bedrock in those times of elementary schooling, the middle colonists could not accommodate themselves, as did the Puritans, to a single school teaching reading and religion to all the children of the neighbourhood. Instead, they depended on parish or parochial schools, each of them free to teach by its own denominational lights. True, for a time New Netherland, with its established Dutch Reformed church, maintained some town schools, but, after the English seized the colony (renaming it New York), such endeavours ceased. Pennsylvania, linguistically and denominationally the most heterogeneous of the colonies, began its educational history by ordering the erection of public schools and the instruction of children. But the ordinance fell prey to powerful sectarian antagonisms, and in 1701 the colony essayed to make peace by sanctioning the establishment of parochial schools.

Like the New Englanders, the middle colonists aspired to establish colleges, but, with no friendly lawmakers to sustain them, they found their task heavily hobbled, and the mid-1700s were upon them before their hopes materialized with the advent, in 1746, of the College of New Jersey (Princeton). There followed King's College (Columbia) in 1754; the College and Academy of Philadelphia (Pennsylvania) in 1755; and Queen's College (Rutgers) in 1766. Common to these schools was their stress on the ancient languages, metaphysics, and divine science. At the same time, however, one discerns signs of a new liberalism. Both Rutgers and Columbia announced their interdenominationalism. Pennsylvania offered courses in physics, and in 1765 it became the first colonial college to sponsor systematic instruction in medicine.

Effects of plantation life on Southern education

The Southern colonies. Unlike New Englanders, Southerners resided not in villages but on widely scattered plantations. For years, town life was impossible and so, per consequence, were town schools. But even had their establishment been feasible, the odds against them were staggering, since the ruling classes, like their analogues overseas in England, were averse to schooling the young under governmental direction. Instead, they regarded education as a personal concern, the affair of parent and church rather than of the state. Left thus to their own devices, Southerners schooled their young to suit their taste, the rich resorting to tutors and private schools and the rest scratching out an education as best they could. Time saw the appearance of a number of free schools serving those who were neither rich nor poor. For the offspring of the low-down and unregarded folk, Virginia enacted its law of 1642. An echo of England's Poor Law, it provided for the "relief of such parents whose poverty extends not to give them [the children] breeding." For this purpose it ordered the creation of a "workhouse school" at James City to which each county was to commit two children of an age of six or over. There, besides being reared as Anglicans, they were to be "instructed in honest and profitable trades and manufactures as also to avoid sloth and idleness." Amended several times, the statute became the model for similar legislation throughout the South.

The first Southern college was founded in Virginia in 1693. William and Mary College was chartered to propagate the "Liberal Arts and the Christian Faith," with particular stress on preparing young men for the Anglican pulpit. As the 18th century swept on, the secular interest that had invaded Harvard appeared in Virginia, and there ensued a waning of the earlier religious motivation. In 1779, led by Thomas Jefferson, the college trustees refurbished the school with chairs in medicine, mathematics, physics, moral philosophy, economics, law, and politics. The chair in divinity was discontinued as "incompatible with freedom in a republic." (A.E.M./R.F.L.)

Newfoundland and the Maritime Provinces. Newfoundland was, during most of this period, under British control, and, though there were settlers even before the 17th century, the island was not considered a settlement colony. Other than for naval training and fishing advantages, the British government had no concern for Newfoundland. Thus, policies were constructed with regard to the rights and advantages of British seamen, while, implicitly as well as in overt regulations, settlement was obstructed and restricted. Destruction from the running French-British military conflicts further discouraged development. These conditions of economic and political diminution of the settlement from outside were aggravated by the usurious conduct of merchants and the corruption of officials and by the national and religious divisions among the inhabitants themselves.

With such substantial problems of mere survival in Newfoundland, it is not surprising that the luxury of formal education was almost absent during this period. Some accounts verify that informal, unorganized efforts were made on an occasional basis to convey minimum schooling to settlers' children, but the only organized effort was that of the Society for the Propagation of the Gospel in Foreign Parts (SPGFP). The SPGFP founded or aided a school in Bonavista in 1722 and in St. John's in 1744 and sponsored schools in more than 20 settlements between 1766 and 1824. Religion was undoubtedly more important than education as such to the society, but its provision of reading materials as well as the mere act of establishing some kind of school filled a notable void in the Newfoundland

Society for the Propagation of the Gospel in Foreign Parts

settlement. Other charitable societies, such as the Society for Improving the Condition of the Poor in St. John's, the Benevolent Irish Society, the Newfoundland School Society (later the Colonial and Continental Church Society), the Wesleyan Society, the Sisters of the Presentation, the Sisters of Mercy, and the Irish Christian Brothers, carried the charity-school work into the 19th century and maintained a thread of education through the colonial "dark ages."

For a time after 1763 the Maritimes were all one colony—Nova Scotia—but Prince Edward Island was separated in 1769 and New Brunswick in 1784. This area comprised a heterogeneous population of French Acadians, English Protestants and others from Europe, Highland Scots, and loyalists from the United States. Each of these groups carried attitudes more or less favourable to education, and the regionalization of these attitudes, together with other conditions, influenced the differential development of education in the area. At the end of the 18th century, for example, New Brunswick, with a high loyalist population promoting political and educational development, probably ranked highest among the Maritime colonies in educational interest.

The first relatively organized attempt at common schooling in the Maritimes was made by the SPGFP, closely connected to the Church of England. The society opened both weekday and Sunday schools, and it might be said that it fostered teacher training in stipulating qualifications for its teachers. Other than SPGFP schools, education in the Maritime colonies was carried on by itinerant teachers and in scattered private-venture schools. Schools for separate ethnic or religious groups were discouraged by the Anglicans, but consistent pressure for such schools did succeed, at least temporarily; for example, in Lunenburg, Nova Scotia, and in Sydney, on Cape Breton Island. A school for blacks was established in Halifax in 1788.

Upper schools were established only toward the end of the 18th century in the Maritimes. As they were established singularly and recruited from a social class rather than from a lower school, there is no clear line of demarcation among the various types as there would be later in an integrated system. Basically, they were Anglican and classical, although the private schools, advertising to as wide a clientele as possible, often included some breadth, extending into practical studies. Probably the most influential of the early attempts were the two Latin grammar schools founded in 1788 and 1789 at Windsor and Halifax, Nova Scotia. The former became associated with King's College, established in Windsor at the same time. Thomas McCulloch's Academy at Pictou, Nova Scotia, and the College of New Brunswick at Fredericton, both founded around the turn of the century, were also early exemplars of higher education. (R.F.L.)

Western education in the 19th century

THE SOCIAL AND HISTORICAL SETTING

From the mid-17th century to the closing years of the 18th century, new social, economic, and intellectual forces steadily quickened—forces that in the late 18th and the 19th centuries would weaken and, in many cases, end the old aristocratic absolutism. The European expansion to new worlds overseas had stimulated commercial rivalry. The new trade had increased national wealth and encouraged a sharp rise in the numbers and influence of the middle classes. These social and economic transformations, joined with technological changes involving the steam engine and the factory system, together produced industrialism, urbanization, and the beginnings of mass labour. At the same time, intellectuals and philosophers were assaulting economic abuses, old unjust privileges, misgovernment, and intolerance. Their ideas, which carried a new emphasis on the worth of the individual—the citizen rather than the subject—helped not only to inspire political revolutions, sometimes successful, sometimes unsuccessful, but, more important, to make it impossible for any government, even the most reactionary, to disregard for long the welfare of the common man. Finally, there was a widespread psychological change: man's confidence in his power to use resources, master nature, and structure his own future was heightened beyond anything known before; and this confidence on a national scale—in the form of nationalism—moved all groups to struggle for the freedom to direct their own affairs.

Education as the responsibility of the state

All these trends influenced the progress of education. One of the most significant results was the gradual acceptance of the view that education ought to be the responsibility of the state. Some countries, such as France and Germany, were inspired by a mixture of national aspiration and ideology to begin the establishment of public educational systems early in the 19th century. Others, such as Great Britain and the United States, under the spell of laissez-faire, hesitated longer before allowing the government to intervene in educational affairs. The school reformers in these countries had to combat the prevailing notion that "free schools" were to be provided only for pauper children, if at all; and they had to convince society that general taxation upon the whole community was the only adequate way to provide education for all the children of all the people.

The new social and economic changes also called upon the schools, public and private, to broaden their aims and curricula. Schools were expected not only to promote literacy, mental discipline, and good moral character but also to help prepare children for citizenship, for jobs, and for individual development and success. Although teaching methods remained oriented toward textbook memorizing and strict discipline, a more sympathetic attitude toward children began to appear. As the numbers of pupils grew rapidly, individual methods of "hearing recitations" by children began to give way to group methods. The monitorial, or Lancasterian, system became popular because, in the effort to overcome the shortage of teachers during the quick expansion of education, it enabled one teacher to use older children to act as monitors in teaching specific lessons to younger children in groups. Similarly, the practice of dividing children into grades or classes according to their ages—a practice that began in 18th-century Germany—was to spread everywhere as schools grew larger.

THE EARLY REFORM MOVEMENT: THE NEW EDUCATIONAL PHILOSOPHERS

The late 18th and 19th centuries represent a period of great activity in reformulating educational principles, and there was a ferment of new ideas, some of which in time wrought a transformation in school and classroom. The influence of Rousseau was profound and inestimable. One of his most famous followers was Pestalozzi, who believed that children's nature, rather than the structure of the arts and sciences, should be the starting point of education. Rousseauist ideas are seen also in the work of Friedrich Froebel, who emphasized self-activity as the central feature of childhood education, and in that of Johann Friedrich Herbart, perhaps the most influential 19th-century thinker in the development of pedagogy as a science.

Influence of Rousseau

Pestalozzi. The theories of the Swiss reformer Johann Heinrich Pestalozzi laid much of the foundation of modern elementary education. Beginning as a champion of the underprivileged, he established near Zürich in 1774 an orphanage in which he attempted to teach neglected children the rudiments of agriculture and simple trades in order that they might lead productive, self-reliant lives. A few years later the enterprise failed, and Pestalozzi turned to writing, producing his chief work on method, *How Gertrude Teaches Her Children,* in 1801, and then began teaching again. Finally in 1805 he founded at Yverdon his famous boarding school, which flourished for 20 years, was attended by students from every country in Europe, and was visited by many important figures of the time, including the philosopher Johann Gottlieb Fichte, the educators Froebel and Herbart, and the geographer Carl Ritter.

The pedagogy of Pestalozzi. In spite of the quantity of his writings, it cannot be said that Pestalozzi ever wrote a complete and systematic account of his principles and methods; an outline of his theories must be deduced from his various writings and his work. The foundation of his doctrine was that education should be organic, meaning that intellectual, moral, and physical education (or, in his

Child-centred education

words, development of "head, heart, and body") should be integrated and that education should draw upon the faculties or "self-power" inherent in the human being. Education should be literally a drawing-out of this self-power, a development of abilities through activity—in the physical field by encouraging manual work and exercises, in the moral field by stimulating the habit of moral actions, and in the intellectual field by eliciting the correct use of the senses in observing concrete things accurately and making judgments upon them. Words, ideas, practices, and morals have meaning only when related to concrete things.

From these overarching principles there followed certain practical rules of educational method. First, experience must precede symbolism. There must be an emphasis on object lessons that acquaint the child with the realities of life; from these lessons abstract thought is developed. What one does is a means to what one knows. This means that the program should be child-centred, not subject-centred. The teacher is to offer help by participating with the child in his activities and should strive to know the nature of the child in order to determine the details of his education. This means that the stages of education must be related to the stages of child development. Finally, intellectual, moral, and physical activities should be as one.

Much of Pestalozzi's pedagogy was influenced by his work with children of the poor. Thus, there was a strong emphasis on education in the home. The development of skills was emphasized, not for their own sake, but in connection with intellectual and moral growth. Manual training was important for the head and heart, as well as for the hand. Whereas the reformers of the Enlightenment and the French Revolution stressed the "emancipation" of the lower classes, Pestalozzi aimed at helping poor people to help themselves. This was social reform, not social revolution.

The influence of Pestalozzi. "The art of education," Pestalozzi claimed, "must be significantly raised in all its facets to become a science that is to be built on and proceeds from the deepest knowledge of human nature." By his own efforts in this direction, he stimulated pedagogical theory and practice to an enormous degree in many parts of the Western world. By his philanthropic efforts on behalf of the poor, he inspired new movements toward the reform of philanthropic educational institutions and the pedagogy applied to such institutions; he created a new methodology for elementary education that was introduced not only into schools but also into programs of teacher education in Europe and America; and by his own example he gave teachers a high professional ethos. Pestalozzi, like few others at any time, recognized and sincerely tried to alter the misery existing in the world. If the Enlightenment saw its pedagogical mission as the spreading of the light of reason, then Pestalozzi showed that it was not reason alone but love above all that would show a way out of the "mire of the world."

Pestalozzi's influence abroad

It is hardly possible to name all of Pestalozzi's disciples—the Pestalozzians—for almost all the pedagogical figures of his time literally or figuratively went to his school. His influence was most profound in Germany, especially in Prussia and Saxony. Generally speaking, in the first half of the 19th century the English school system was completely under the influence of the disciplinarian monitorial systems of Bell and Lancaster. Pestalozzi for most Englishmen was "a distressing type of the German" and "an idealistic dreamer," as some critics put it. Nevertheless, he exercised some influence in England through James Pierrepont Greaves and the London Infant School Society and through Charles and Elizabeth Mayo and the Home and Colonial School Society. In the United States Pestalozzianism was introduced by a Philadelphia scientist and philanthropist, William Maclure, one of the sponsors of the utopian colony at New Harmony, Ind., and by Joseph Neef, who opened a school near Philadelphia.

In Switzerland itself, in Hofwil near Bern, Philipp Emanuel von Fellenberg founded an institution for the education of the poor. He tried to build up a kind of pedagogical province or miniature state, in which work was the means of self-help and in which the pedagogical program was the joint responsibility of teachers and pupils.

Froebel and the kindergarten movement. Next to Pestalozzi, perhaps the most gifted of early 19th-century educators was Froebel, the founder of the kindergarten movement and a theorist on the importance of constructive play and self-activity in early childhood. He was an intensely religious man who tended toward pantheism and has been called a nature mystic. Throughout his life he achieved very little literary fame, partly because of the style of his prose and philosophy, which is so academic and obscure that it is difficult to read and sometimes scarcely comprehensible.

In early life, Froebel tried various kinds of employment until in 1805 he met Anton Gruner, a disciple of Pestalozzi and director of the normal school at Frankfurt am Main, who persuaded him to become a teacher. After two years with Gruner, he visited Pestalozzi at Yverdon, studied at Göttingen and Berlin, and eventually determined upon establishing his own school, founded on what he considered to be psychological bases. The result in 1816 was the Universal German Educational Institute at Griesheim, transferred the following year to Keilhau, which constituted a kind of educational community for Froebel, his friends, and their wives and children. To this period belongs *The Education of Man* (1826), his most important treatise, though typical of his obscurantism. In 1831 he was again in Switzerland, where he opened a school, an orphanage, and a teacher-training course. Finally, in 1837, upon returning to Keilhau, he opened his first *Kindergarten,* or "garden of children," in nearby Bad Blankenburg. The experiment attracted wide interest, and other kindergartens were started and flourished, despite some political opposition.

The first kindergarten

The pedagogy of Froebel. Froebel's pedagogical ideas have a mystical and metaphysical context. He viewed man as a child of God, of nature, and of humanity who must learn to understand his own unity, diversity, and individuality, corresponding to this threefold aspect of his being. On the other hand, man must understand the unity of all things (the pantheistic element).

> Education consists of leading man, as a thinking, intelligent being, growing into self-consciousness, to a pure and unsullied, conscious and free representation of the inner law of Divine Unity, and in teaching him ways and means thereto.

Education had two aspects: the teacher was to remove hindrances to the self-development or "self-activity" of the child, but he was also to correct deviations from what man's experience has taught is right and best. Education is thus both "dictating and giving way." This means that ordinarily a teacher should not intervene and impose mandatory education, but when a child, particularly a child of kindergarten age, is restless, tearful, or willful, the teacher must seek the underlying reason and try to eradicate the uncovered hindrance to the child's creative development. Most important, the teacher's dictating and giving way should not flow from the mood and caprices of the teacher. Behaviour should be measured according to a "third force" between teacher and child, a Christian idea of goodness and truth.

School, for Froebel, was not an "establishment for the acquisition of a greater or lesser variety of external knowledge"; actually, he thought children were instructed in things they do not need. School instead should be the place to which the pupil comes to know the "inner relationship of things," "things" meaning God, man, nature, and their unity. The subjects followed from this: religion, language and art, natural history, and the knowledge of form. In all these subjects the lessons should appeal to the pupil's interests. It is clear that, in Froebel's view, the school is to concern itself not primarily with the transmission of knowledge but with the development of character and the provision of the right motivation to learn.

Froebel's emphasis on play

Froebel put great emphasis on play in child education. Just like work and lessons, games or play should serve to realize the child's inner destiny. Games are not idle time wasting; they are "the most important step in the development of a child," and they are to be watched by the teachers as clues to how the child is developing. Froebel was especially interested in the development of toys for children—what he called "gifts," devised to stim-

ulate learning through well-directed play. These gifts, or playthings, included balls, globes, dice, cylinders, collapsible dice, shapes of wood to be put together, paper to be folded, strips of paper, rods, beads, and buttons. The aim was to develop elemental judgment distinguishing form, colour, separation and association, grouping, matching, and so on. When, through the teacher's guidance, the gifts are properly experienced, they connect the natural inner unity of the child to the unity of all things: *e.g.*, the sphere gives the child a sense of unlimited continuity, the cylinder a sense both of continuity and of limitation. Even the practice of sitting in a circle symbolizes the way in which each individual, while a unity in itself, is a living part of a larger unity. The child is to feel that his nature is actually joined with the larger nature of things.

The kindergarten movement. The kindergarten was unique for its time. Whereas the first institutions for small children that earlier appeared in Holland, Germany, and England had been welfare nursery schools or day-care centres intended merely for looking after children while parents worked, Froebel stood for the socializing or educational idea of providing, as he put it in founding his kindergarten, "a school for the psychological training of little children by means of play and occupations." The school, that is, was to have a purpose for the children, not the adults. The curriculum consisted chiefly of three types of activities: (1) playing with the "gifts," or toys, and engaging in other occupations designed to familiarize children with inanimate things, (2) playing games and singing songs for the purpose not only of exercising the limbs and voice but also of instilling a spirit of humanity and nature, and (3) gardening and caring for animals in order to induce sympathy for plants and animals. All this was to be systematic activity.

The kindergarten plan to meet the educational needs of children between the ages of four and six or seven through the agency of play thereafter gained widespread acceptance. During the 25 years after Froebel's death in 1852, kindergartens were established in leading cities of Austria, Belgium, Canada, Germany, Great Britain, The Netherlands, Hungary, Japan, Switzerland, and the United States. In Great Britain the term infant school was retained for the kindergarten plan, and in some other countries the term crèche has been used.

Widespread acceptance of kindergartens

Herbart. Johann Friedrich Herbart was a contemporary of Froebel and other German Romanticists, but he can hardly be put into the ranks of such pedagogues. During his lifetime his sober, systematic "philosophical realism" found little approval; and only posthumously, during the latter half of the 19th century, did his work achieve great importance. He is regarded as one of the founders of theoretical pedagogy, injecting both metaphysics and psychology into the study of how people learn.

The psychology and pedagogy of Herbart. As a young man of 18, Herbart had studied at the University of Jena under the idealist philosopher Fichte. It was a long while before he broke from the spell of Fichte's teachings and turned to philosophical realism, which asserts that underlying the world of appearances there is a plurality of things or "reals." Change consists simply in the alteration in the relations between these reals, which resist the changed relationships as a matter of self-preservation.

Ideas, like things, always exist and always resist change and seek self-preservation. It is true that some ideas may be driven below the threshold of consciousness; but the excluded ideas continue to exist in an unconscious form and tend, on the removal of obstacles (as through education), to return spontaneously to consciousness. In the consciousness there are ideas attracting other ideas so as to form complex systems. These idea masses correspond to the many interests of the individual (such as his home and his hobbies) and to broader philosophical and religious concepts and values. In the course of mental development certain constellations of ideas acquire a permanent dominance that exercises a powerful selective facilitating influence upon the ideas struggling to enter or reenter the consciousness.

In his systematic account of the nature of education, Herbart conceived the process as beginning with the idea masses that the child has previously acquired from experience and from social intercourse. The teacher creates knowledge from the former and sympathy from the latter. The ultimate objective is the formation of character by the development of an enlightened will, capable of making judgments of right and wrong. Moral judgments (like reals) are absolute, springing from contemplation, incapable of proof and not requiring proof. Ethics, in other words, is the ultimate focus of pedagogy.

In the classroom, it is the aim of the lessons to introduce new conceptions, to bind them together, and to order them. Herbart speaks of "articulation," a systematic method of constructing correct, or moral, idea masses in the student's mind. First the student becomes involved in a particular problem; then he considers its context. Each of these two stages has a phase of rest and of progress, and thus there are four stages of articulation: (1) clarification, or the static contemplation of particular conceptions, (2) association, or the dynamic linking of new conceptions with old ones, (3) systematization, or the static ordering and modification of what in the conceptions are deemed of value, and (4) methodization, or the dynamic application and recognition of what has been learned. Herbart phrased this system of instruction only in very general terms, but his successors tended to turn this framework into a rigid schedule that had to be applied to every lesson. Herbart himself warned:

Articulation, or the systematization of lessons

> We must be familiar with them [the methods], try them out according to circumstances, alter, find new ones, and extemporize; only we must not be swallowed up in them nor seek the salvation of education there.

The Herbartians. Herbart's basing of educational methods on an understanding of mental processes or psychological considerations, his view that psychology and moral philosophy are linked, and his idea that instruction is the means to moral judgment had a large place in late 19th-century pedagogical thought. Among Herbart's followers were Tuiskon Ziller in Leipzig (who was the founder of the Association for Scientific Pedagogy) and Wilhelm Rein in Jena. From 1895 to 1901 a National Herbart Society for the Scientific Study of Education flourished in the United States; John Dewey was a major critic of Herbartianism in its proceedings.

Ziller's ideas are representative of the Herbartians. He insisted that all parts of the curriculum be closely integrated and unified—history and religion forming the core subjects on which everything else was hinged. The sequence of instruction was to be adjusted to the psychological development of the individual, which was seen as corresponding to the cultural evolution of mankind in stages from primitive savagery to civilization. His main aim in education, like the aim of most Herbartians, was promoting character building, not simply knowledge accumulation.

Other German theorists. In the history of pedagogy there is no period of such fruitfulness as the 19th century in Germany. In addition to Herbart, Froebel, Pestalozzi (in German Switzerland), and their followers, there were scores of the most important writers, philosophers, and theologians contributing their ideas on education—including Friedrich Schiller, Johann Wolfgang von Goethe, G.W.F. Hegel, Friedrich Ludwig Jahn, Johann Paul Friedrich Richter, Ernst Moritz Arndt, and Friedrich Nietzsche. To list the many ideas and contributions of these figures and others is impossible here, but it is worthwhile to suggest briefly the work of three men—Johann Gottlieb Fichte, Friedrich Schleiermacher, and Wilhelm von Humboldt—representing three divergent views.

When the great heterodox University of Berlin was founded in 1809, Fichte became one of its foremost professors and a year later its second rector, having already achieved fame throughout Germany as an idealist philosopher and fervent nationalist. At a time when Napoleon had humbled Prussia, Fichte in Berlin delivered the powerful *Addresses to the German Nation* (1807–08), full of practical views on national recovery and glory, including suggestions on the complete reorganization of the German schools along Pestalozzian lines. All children would be educated—and would be educated by the state. Boys and girls would be taught together, receiving virtually the same

Fichte's ordered education

education. There would be manual training in agriculture and the industrial arts, physical training, and mental training, the aim of which would be not simply the transmission of measures of knowledge but rather the instillation of intellectual curiosity and love and charity toward all men. Unlike Pestalozzi, however, Fichte was wary of the influence of parents and preferred educating children in a "separate and independent community," at least until a new generation of parents had arisen, educated in the new ideas and ideals. Here was an apparent revival of Plato's idea of a strictly ordered, authoritarian state.

Another of the founders of the University of Berlin (teaching there from 1810 to 1834) was the Protestant theologian Friedrich Schleiermacher, who sounded a very modern note by offering a social interpretation of education. Education, in his view, was an effort on the part of the older generation to "deliver" the younger generation into the four spheres of life—church, state, social life, and science. Education, however, not only assumes its organization in terms of these four areas of life but also serves to develop and influence these areas.

Perhaps more than any other individual, the philologist and diplomat Wilhelm von Humboldt was responsible for the founding of the University of Berlin. Supported by the king of Prussia, Frederick William III, he adopted for it principles that raised it to a foremost place among the universities of the world—the most important principle being that no teacher or student need adhere to any particular creed or school of thought. This academic freedom survived in Germany despite its temporary suspension and Humboldt's dismissal by a reactionary Prussian government in 1819. Philosophically and pedagogically, Humboldt was himself a humanist—a part of a wave of what were called new humanists—who reasserted the importance of studying the classical achievements of humanity in language, literature, philosophy, and history. The aim of education in these terms was not the service of society or the state but rather the cultivation of the individual.

Humboldt's humanism

French theorists. At this time there were two men in France who were making their names through the introduction of new methods—Jean-Joseph Jacotot and Édouard Séguin. Jacotot was a high-school teacher, politician, and pedagogue, whose main educational interests focused on the teaching of foreign languages. "You learn a foreign language," he said, "as you learn your mother-language." The pupil is confronted with a foreign language; he learns a text in the language almost by heart, compares it with a text in his own native language, and then tries gradually to free himself from the comparison of texts and to construct new combinations of words. The teacher controls this learning by asking questions. "My method is to learn one book and relate all the others to it." The learning of grammar came later.

Jacotot's method emphasized first the practical side and then the rule, constant repetition, and self-activity on the part of the pupils. Controversy arose, however, over his two basic theses: (1) that everyone has the same intelligence, differences in learning success being only a case of differences in industry and stamina, and (2) that everything is in everything: "Tout est dans tout," which suggests that any subject or book is analogous to any other.

The doctor and psychologist Édouard Séguin developed a pedagogy for pupils of below-average intelligence. Historically, scientific attempts to educate mentally retarded children had begun with the efforts of a French doctor, Jean-Marc-Gaspard Itard, during the latter part of the 18th century. In his classic book, *The Wild Boy of Aveyron* (1801), Itard related his five-year effort to train and educate a boy found, at about the age of 11, running naked and wild in the woods of Aveyron. Later, Séguin, a student of Itard, devised an educational method using physical and sensory activities to develop mental processes. Limbs and the senses were, in his view, a part of the whole personality, and their development was a part of the whole human education. His method was a specific adaptation of the idea that the development of intellectual and moral distinctions grows out of sensory experience.

Education of the mentally retarded

Spencer's scientism. The English sociologist Herbert Spencer was perhaps the most important popularizer of science and philosophy in the 19th century. Presenting a theory of evolution prior to Charles Darwin's *On the Origin of Species by Means of Natural Selection,* Spencer argued that all of life, including education, should take its essential lessons from the findings of the sciences. In *Education: Intellectual, Moral, and Physical* (1860) he insisted that the answer to the question "What knowledge is of most worth?" is the knowledge that the study of science provides. While the educational methodology Spencer advocated was a version of the sense realism espoused by reformers from Ratke and Comenius down to Pestalozzi, Spencer himself was a social conservative. For him, the value of science lies not in its possibilities for making a better world but in the ways science teaches man to adjust to an environment that is not susceptible to human engineering. Spencer's advocacy of the study of science was an inspiration to the American Edward Livingston Youmans and others who argued that a scientific education could provide a culture for modern times superior to that of classical education. (H.-J.I./J.J.Ch.)

DEVELOPMENT OF NATIONAL SYSTEMS OF EDUCATION

The great changes in Europe in the 19th century included, among other things, the further consolidation of national states, the spread of modern technology and industrialization, and increasing secularization. These changes had consequences for the design of school systems. National school systems had to be conceived and organized. Alongside the older schools, including elementary schools, Latin, or grammar, secondary schools, and universities, there developed so-called modern schools that stressed the exact sciences and modern languages, reflecting the new technological and commercial age. Vocational schools also appeared in greater numbers. The influence of the church was increasingly repressed, and the influence of the state on the school system correspondingly grew stronger. The ideal of universal education—education for all—became more and more a reality.

Germany. Luther's pronouncements on the educational responsibilities of the individual had no doubt helped create that healthy public opinion that rendered the principle of compulsory school attendance acceptable in Prussia at a much earlier date than elsewhere. State intervention in education was almost coincident with the rise of the Prussian state. In 1717 Frederick William I ordered all children to attend school if schools were available to them. This was followed in 1736 by edicts for the establishment of schools in certain provinces, in 1763 by Frederick II the Great's regulation asserting the principle of compulsory school attendance, and in 1794 by a codification of Prussian law recognizing the principle of state supremacy in education.

Humboldt's reforms. The schools, however, had established a traditional classical curriculum that ignored the changing needs of life and fields of knowledge. No effective reorganization of the educational system was carried out until after the disaster of the Battle of Jena (1806), during the Napoleonic Wars, which brought about the virtual collapse of Prussia. Fichte delivered his *Addresses to the German Nation* at this time, appealing to the spirit of patriotism over a selfish individualism. He advocated a nationalism to be cultivated and enhanced by controlling the education of the young. In the period of governmental reform which came about, one of the first acts of the prime minister Freiherr Karl vom Stein in 1807 was to abolish certain semi-ecclesiastical schools and to place education under the Ministry of the Interior, with Wilhelm von Humboldt at the head of a special section. Humboldt's policy in secondary education was a compromise between the narrow philological pedantry of the old Latin schools and the large demands of the new humanism that he espoused. The measure introduced by Humboldt in 1810 for the state examination and certification of teachers checked the then-common practice of permitting unqualified theological students to teach in the schools and raised the teaching profession to a high level of dignity and efficiency, placing Prussia in the forefront of educational progress. It was also a result of the initiative of Humboldt that the methods of Pestalozzi were

Reforms inspired by the Napoleonic disasters

introduced into the teachers' seminaries. To this period also belongs the revival, in 1812, of the *Abitur* (the school-leaving examination), which had fallen into abeyance.

Developments after 1815. The period that succeeded the peace of 1815 was one of political reaction, and not until the 1830s were there further significant reforms. In 1834, for example, an important step was taken in regard to secondary education by making it necessary for candidates for the learned professions, as well as for the civil service and for university studies, to pass the leaving examination of the *Gymnasien,* the classical secondary schools. Thus, through the leaving examination, the state held the key to the liberal careers and was thereby able to impose its own standards upon all secondary schools.

In connection with the so-called Kulturkampf, or struggle between the state and the Roman Catholic church, the school law of 1872 reasserted the absolute right of the state alone to the supervision of the schools. Nevertheless, the Prussian system remained both for Catholics and for Protestants essentially denominational. On the elementary level, in particular, the mixed school was established only when the creeds were so intermingled that a confessional school was impracticable. In all cases the teachers were appointed with reference to religious faith; religious instruction was given in school hours and was inspected by the clergy.

Types of German secondary schools

The official classification, or grading according to the type of curriculum, of secondary schools in Prussia (and throughout Germany) was very precise. The following were the officially recognized types: (1) the classical nine-year *Gymnasium,* with a curriculum that included Latin, Greek, and a modern language, (2) the semiclassical nine-year *Realgymnasium,* with a more modern curriculum that included, in addition to Latin and modern languages, the natural sciences and mathematics, and (3) the modern six-year *Realschule* or nine-year *Oberrealschule,* with a curriculum of sciences and mathematics.

The differentiation between the types was the result of a natural educational development corresponding to the economic changes that transformed Prussia from an agricultural to an industrial state. The classical schools long retained their social prestige and a definite educational advantage in that only their pupils were admissible to the universities. From the foundation of the German Empire in 1871 the history of secondary education was largely concerned with a struggle for a wider recognition of the work of the newer schools. The movement received a considerable impetus by the action of Emperor William II, who summoned a school conference in 1890 at which he set the keynote: "It is our duty to educate young men to become young Germans and not young Greeks or Romans." New schedules were framed in which the hours devoted to Latin were considerably reduced, and no pupil could obtain a leaving certificate without a satisfactory mark in the mother tongue. The reform lasted only a single school generation. In 1900 equality of privileges was granted to three types of schools, subject to certain reservations: the theological faculties continued to admit only students from classical schools, and the pupils of the *Oberrealschule* were excluded by their lack of Latin from the medical faculties; but insofar as Latin was required for other studies, such as law or history, it could be acquired at the university itself.

Girls' schools. In Prussia, as elsewhere, the higher education of girls lagged far behind that of boys and received little attention from the state or municipality, except insofar as the services of women teachers were needed in the elementary schools. Thus it came about that in Prussia secondary schools for girls were dealt with administratively as part of the elementary-school system. After the establishment of the German Empire in 1871, a conference of directors and teachers of these schools was held at Weimar and put forth a reasoned plea for better organization and improved status. The advocates of reform, however, were not at unity in their aims; some wished to lay stress on ethical, literary, and aesthetic training; others stressed intellectual development and claimed an equal share in all the culture of the age. Even the women teachers fought an unequal battle, for all the school heads and a large part of the staff were men, usually academically trained. The women continually demanded a larger share of the work, and this was secured by the establishment of a new higher examination for women teachers. University study, though not prescribed, was in fact essential, and yet women had not the right of access to the university in Germany. They were allowed to take the leaving examination, for which private institutions prepared them, but their admission to the university rested with the professor. Not until the 20th century were desired changes achieved.

The new German universities. Unquestionably one of the greatest worldwide influences exercised by German education in the 19th century was through its universities, to which students came from all over the world and from which every land drew ideas for the reformation of higher education. To understand this, one must be aware of the state of higher education in most countries in the 19th century. Although the century witnessed a steady expansion of scientific knowledge, the curriculum of the established universities went virtually untouched. Higher education followed a single dimension. This was the century of the scientists Michael Faraday, Hermann von Helmholtz, James Prescott Joule, Charles Darwin, Joseph Lister, Wilhelm Wundt, Louis Pasteur, and Robert Koch. Yet, until the end of the century, most of the significant research was done outside the walls of higher educational institutions. In Great Britain, for instance, it was the Royal Society and other such societies that fostered advanced studies and encouraged research. The basic curriculum of colleges and universities remained nontechnical and nonprofessional. The English cardinal John Henry Newman, lecturing in Dublin on *The Idea of a University* in 1852, stated that the task of the university was broadly to prepare young men "to fill any post with credit, and to master any subject with facility." The university ought not to attempt professional and technical education.

Condition of 18th- and 19th-century higher education

While Newman's words epitomized the views held in most of Europe and America, some of the new universities in Germany were moving toward the expansion of the educational enterprise. In 1807 Fichte had drawn up a plan for the new University of Berlin, which Humboldt two years later was able to realize in its founding. The school was dedicated to the scientific approach to knowledge, to the combination of research and teaching, and to the proliferation of academic pursuits; and its ideal was adopted in the founding or reconstitution of other universities—Breslau (1811), Bonn (1818), Munich (1826). By the third quarter of the 19th century the influence of German *Lernfreiheit* (freedom of the student to choose his own program) and *Lehrfreiheit* (freedom of the professor to develop the subject and to engage in research) was felt throughout the academic world. The unity of the universities, for better or worse, was more and more dissolved by the fragmentation of subjects into different branches. Some critics would eventually condemn what they considered to be the excesses of the free elective system and the extreme departmentalization of research and curricula. Much of the debate, however, would centre on the general education of undergraduates. In the meantime, the conviction, fathered in Germany, that research is a responsibility of universities was to inspire the founders of universities in the United States in the late 19th century.

Lernfreiheit and *Lehrfreiheit*

France. In France the Jesuit schools and the schools of other teaching orders created at the time of the Renaissance had reconciled the teaching of the new humanism with the established doctrines of the Roman Catholic church and flourished with special brilliance. But, despite the changes brought about by the Renaissance and the attention given to the sciences in the 17th and 18th centuries, it was not until the advent of the French Revolution that the universal right to education was proclaimed (1791).

That principle was compromised when Napoleon came to power, however. Although he maintained that the matter of education was an important issue and thought that a common culture with common ideals was essential to nation-building, he felt that, from a political standpoint, the bourgeoisie and upper classes were most important. His national education system therefore served children of those classes. This led to reorganization of the structure of

Napoleonic system of education

secondary and higher education in a unified state system, with secondary schools maintained by the communes, and with state lycées, universities, and special institutions of higher education. Within this structure the rector of a university headed a teaching body, recruited by the state and supervised by an inspectorate, ranging through various grades up to the university council. Grades of proficiency in studies, from simple certificates to the degrees of *baccalauréat, licence,* and doctorate were awarded on the result of examinations, and these tests were made a necessary condition of entry into such professions as medicine, law, and teaching. This structure, despite many modifications, has survived until modern times.

Development of state education. French educational history in the 19th century is essentially the story of the struggle for the freedom of education, of the introduction at the secondary level of the modern and scientific branches of learning, and, under the Third Republic, of the establishment of primary education, at once secular and compulsory, between the ages of six and 12. There were also a middle education between the ages of 13 and 16 and, finally, a professional and technical education.

Under the restoration of the monarchy in 1814, education fell inevitably under the control of the church; but, during the bourgeois monarchy of Louis Philippe, a law was passed in 1833 that laid the foundations of modern primary instruction, obliging the communes to maintain schools and pay the teachers. The higher primary schools that were founded were suppressed by Roman Catholic conservatives in 1850 (their restoration later constituted one of the great positive services rendered by the Third Republic to the cause of popular education). The 1850 law restored the "liberty of teaching" that, in effect, meant free scope for priestly schools, but it also made provision for separate communal schools for girls, for adult classes, and for the technical instruction of apprentices. In 1854 France

Centralization of French education

was divided for purposes of educational administration into 16 districts called *académies,* each administered by a rector and each with a university at the apex of the educational structure. The rector not only was made the chief administrator of the university but also was responsible for secondary and higher education within his *académie;* he nominated candidates for administrative positions in his area, appointed examination committees, supervised examination content and procedures, and presided over an academic council. Unlike the political division in some other countries, the *académies* were given little power or authority of their own; rather, they were administrative arms of the national ministry of education.

After the Franco-Prussian War, the Third Republic addressed itself to the organization of primary instruction as "compulsory, free, and secular." The law of 1878 imposed on communes the duty of providing school buildings and provided grants-in-aid. The national government also henceforth paid salaries throughout the public sector of education. In 1879 a law was passed compelling every department to maintain training colleges for male and female teachers. The law of 1881 abolished fees in all primary schools and training colleges; the law of 1882 established compulsory attendance; and, finally, the law of 1886 enacted that none but lay persons should teach in the public schools and abolished in those schools all distinctively religious teaching.

Secondary education. In European systems of education, secondary education was preeminently a preparation for the university, with aims and ideals of general culture that differentiated it radically and at the very outset from education of the elementary type. Down to the beginning of the 20th century, the French system could be regarded as a typical and extreme example of the European theory.

European dual plan

The characteristic European organization has been called the dual plan: elementary and secondary education were distinct types, and only a minority of the elementary-school pupils passed on to the secondary schools, generally only if they were bright and could win scholarships through a competitive examination. The secondary schools were of two kinds: lycées and communal colleges. The lycées, maintained by tuition fees and state scholarships, taught the ancient languages, rhetoric, logic, ethics, mathematics, and physical science. The communal colleges, established by municipalities or individuals and maintained by tuition fees, offered a partial lycée curriculum, featuring Latin, French, mathematics, history, and geography. Pupils who did not complete a secondary education program generally entered civil service or other white-collar occupations. With the development of commerce and industry in the 19th century, France instituted the *écoles primaires supérieures,* or "higher primary schools," for those who did not go on to universities but who needed a better education than the primary schools could give. The curricula of these schools were somewhat more advanced than those of the primary schools; pupils remained longer (up to the age of 16) and were prepared for employment in business as white-collar workers but generally at a lower level than pupils who came from the lycées. In effect, the different types of schools tended to maintain class cleavages since students of the secondary schools enjoyed higher social and occupational prestige than those of the upper primary schools.

The foundation of secondary schools for girls was in its way one of the most notable achievements of the Third Republic. It was inaugurated by the law of Dec. 22, 1880, called after its author the Loi Camille Sée. Until World War II, the curricula were different from those of the boys' schools, and the course of study was only five years. There were no ancient languages, and mathematics was not carried to so high a level as in the boys' lycées.

England. Influenced by doctrines of laissez-faire, England hesitated a long time before allowing the state to intervene in educational affairs. At the beginning of the 19th century, education was regarded as entirely the concern of voluntary or private enterprise, and there was much unsystematic philanthropy. Attempts were made to channel and concentrate it, and many hoped that the Church of England and the dissenting churches would join in a concerted effort to provide a national system of elementary education on a voluntary basis. But discordant views prevented such cooperation, and two voluntary societies were founded, one representative of the Church of England and the other of dissent. In 1829 the Roman Catholics were emancipated by law from disabilities they had long suffered, and so they also were able to provide voluntary schools. Other religious bodies joined in the effort to meet the growing need for elementary schools, but it was soon evident that voluntary finance would not be equal to this formidable task. In 1833 the government made a small building grant to these societies, and in this modest way state intervention began. Six years later a committee of the Privy Council was established to administer the state grants, now made annually, and to arrange for the inspection of voluntary schools aided from public funds. The work involved led to the establishment of a small central education department, which was the beginning of the ministry of education.

Laissez-faire and English voluntary education

Matthew Arnold was influential in pressing upon the English conscience the importance of public education for the state. While serving as inspector of elementary schools from 1851 to 1886, he studied European school systems and contrasted the meagre educational contributions of the English state with the more generous ones of Continental states.

Elementary Education Act. England prolonged its reliance on voluntary initiative for year after year as population increased, and, with the growing industrialization, people crowded into the new towns. At last in 1870 Parliament, after long, acrimonious debates, passed an Elementary Education Act, the foundation upon which the English educational system has been built. Religious teaching and worship were the crucial issues in the debates, and the essentials of the settlement agreed upon were (1) a dual system of voluntary and local-authority schools and (2) careful safeguards to ensure as far as possible that no child would receive religious teaching that was at variance with the wishes of his parents. It was left to the school boards—as these first local education authorities were called—to decide on an individual basis whether to make elementary education compulsory in their districts. In 1880, however, it was made compulsory throughout

England and Wales, and in 1891 fees were abolished in all but a few elementary schools.

Secondary and higher education. Secondary education, however, was still left to voluntary and private enterprise. Attention was focused on the "public" schools (independent secondary schools such as Eton and Harrow, usually for boarders from upper- and well-to-do middle-class homes), which under the leadership of outstanding headmasters such as Thomas Arnold were thoroughly reformed. As headmaster of Rugby School (1828–42), Arnold is credited with changing the face of public education in England by instilling a spirit of moral responsibility and intellectual integrity grounded in Christian ethics. Arnold's aims of school life—religious and moral principles, gentlemanly conduct, and intellectual ability—where to have an enduring influence on the English public-school system.

Several new universities were founded during the 19th century, and the latter half of it saw the founding of a number of girls' high schools and boarding schools offering an education that was comparable to that available in boys' public schools and grammar schools. Several training colleges for teachers were established by voluntary agencies, and universities and university colleges toward the end of the century undertook the training of postgraduates as teachers in departments of education created for this purpose.

Russian reform and reaction

Russia. Influenced by the disintegration of the serf system, the trend toward industrialization and modernization, and the democratic ideas of the French Revolution, Tsar Alexander I at the beginning of the 19th century tried to institute new educational reforms. The statutes of 1803 and 1804 followed the pattern set by Peter I the Great and Catherine II the Great in the 18th century for utilitarian, scientific, and secular education. The old Catherinian schools were remodeled and new schools founded. Schools were to be free and under state control. Rural peasants were to be taught reading, writing, arithmetic, and elements of agriculture at the parochial schools (*prikhodskiye uchilishcha*); pupils in the district schools of urban areas (*uyezdnye uchilishcha*) and the provincial schools (*gimnazii*) were to be prepared for careers as civil servants or for other white-collar occupations (law, political economy, technology, and commerce). The elementary and secondary schools were integrated with the universities.

Nicholas I, coming to the throne in 1825, considered this democratic trend harmful and decreed that:

> It is necessary that in every school the subjects of instruction and the very methods of teaching should be in accordance with the future destination of pupils, that nobody should aim to rise above that position in which it is his lot to remain.

A new statute of 1828 decreed that parochial schools were intended for the peasants, the district schools for merchants and other townspeople, and *gimnazii* for children of the gentry and civil servants. Instruction in the *gimnazii* in Latin and Greek was increased. Although the legislation of Nicholas I established a class system, the utilitarian character of the whole system remained.

The Russian radical intelligentsia was fiercely opposed to the privileged schools for the gentry and demanded the reestablishment of a democratic system with a more modern curriculum in secondary schools. This was coupled with the demand for the emancipation of the serfs and the equality of women in education. The new tsar in 1855, Alexander II, inaugurated a period of liberal reforms. The serfs were emancipated in 1861, and thus all social restrictions were removed. A new system of local government in rural areas (*zemstvo*) was enacted with a right to found schools for the peasantry, now free. Combined efforts of the government, *zemstva*, and peasant communities produced a growth of schools in the rural areas. The utilitarian trend was evident in the establishment of technical schools with vocational differentiation. The education of women was promoted, and the first higher courses for women were founded in main cities.

The reign of Alexander II, which was later marked by reactionary measures and political oppression, ended in his assassination in 1881 by the terrorist branch of the Narodniki revolutionary organization. A period of reaction followed under his successor, Alexander III. All reforms were suspended, and the growth of educational institutions was interrupted. The chief procurator of the Holy Synod attempted to build up a rival system of parochial schools under the control of the orthodox clergy; and the minister of public instruction tried to return to the class system of Nicholas I. These reactionary measures set back the growth of education. Four-fifths of all children were deprived of education. The result was that at the turn of the century nearly 70 percent of Russia's male population and 90 percent of its female population were illiterate (1897 census). The aboriginal dwellers of Russia's national outskirts (more than one-half of the country's population) were almost totally illiterate. (J.J.Ch.)

American land-grant colleges

The United States. Administered locally everywhere, schooling of the United States's masses in the republic's younger days was immensely diverse. In New England, primary schooling enjoyed public support. In the South, apart from supplying a meagre learning to pauper children, the states abstained from educational responsibility. In the middle states elementary schools were sometimes public; more often they were parochial or philanthropic. Only beyond the Alleghenies was there any federal provision for education. There, under the Articles of Confederation, the Ordinance of 1787 reserved a plot of land in every prospective township for the support of education. The measure not only laid the groundwork for education in the states of the Ohio Valley and the Great Lakes, it also became a precedent for national educational aid. Thus, in 1862 the Morrill Act granted every state establishing a public agricultural college 30,000 acres (12,000 hectares) of public land for each of its lawmakers in Congress. Since then some 12 million acres (five million hectares) have been distributed, on which some 70 of the so-called land-grant colleges currently flourish.

Several of the Founding Fathers expressed belief in the necessity of public education, but only Thomas Jefferson undertook to translate his conviction into actuality. Convinced that democracy can be effective only in the hands of an enlightened people, he offered Virginia's lawgivers a plan in 1779 to educate schoolchildren at public cost for three years and a few gifted boys beyond that. The proposal encountered resistance from both the ruling classes and the clergy; they regarded instruction as a private or an ecclesiastical prerogative. Jefferson's plan was rejected, as was another he submitted some 40 years later. Although his ideas enlightened educational thought throughout the country, only one of Jefferson's dreams reached actuality in his lifetime: the University of Virginia opened in 1825, the most up-to-date institution of its sort, the first frankly secular university in America and the closest to a modern-day conception of a state university.

The educational awakening. When Jefferson died in 1826 the nation stood on the threshold of a stupendous transformation. During the ensuing quarter century it expanded enormously in space and population. Old cities grew larger and new ones more numerous. The era saw the coming of the steamboat and the railroad. Commerce flourished and so did agriculture. The age witnessed the rise of the common man with the right to vote and hold office. It was a time of overflowing optimism, of dreams of perpetual progress, moral uplift, and social betterment.

The common school

Such was the climate that engendered the common school. Open freely to every child and upheld by public funds, it was to be a lay institution under the sovereignty of the state, the archetype of the present-day American public school. Bringing the common school into being was not easy. Against it bulked the doctrine that any education which excluded religious instruction—as all state-maintained schools were legally compelled to do—was godless. Nor had there been any great recession of the contention that education was not a proper governmental function and for a state to engage therein was an intrusion into parental privilege. Still more distasteful was the fact that public schooling would occasion a rise in taxes.

Yet the common school also mustered some formidable support, and finally, in 1837, liberal Massachusetts lawmakers successfully carried through a campaign for a

state board of education. It is especially to Horace Mann, the board's first secretary, that Massachusetts credits its educational regeneration. To gather data on educational conditions in Massachusetts, Mann roved the entire commonwealth. He lectured and wrote reports, depicting his dire findings with unsparing candour. There were outcries against him, but when Mann resigned, after 12 years, he could take pride in an extraordinary achievement. During his incumbency, school appropriations almost doubled. Teachers were awarded larger wages; in return they were to render better service. To help them Massachusetts established three state normal schools, the first in America. Supervision was made professional. The school year was extended. Public high schools were augmented. Finally, the common school, under the authority of the state, though still beset by difficulties, slowly became the rule.

What Mann accomplished in Massachusetts, Henry Barnard (1811–1900) achieved in Connecticut and Rhode Island. More reserved than Mann, Barnard has come down the ages as the "scholar of the educational awakening." He became the first president of the Association for the Advancement of Education and editor of its *American Journal of Education,* in whose 30 volumes he discussed virtually every important pedagogical idea of the 19th century.

Similar campaigns were under way in other areas. In Pennsylvania the assault centred on the pauper school; in New York it was against sectarianism. On the westward-moving frontier, old educational ideas and traditions had to compete in an environment antagonistic to privilege and permanence. There was controversy everywhere, however, over the state's right to assume educational authority and especially its power to levy school taxes. Future handling of this issue in the West was foretold in 1837, when Michigan realized a state-supported and state-administered system of education in which the state university, the University of Michigan under the leadership of Henry Tappan, played an integral part.

The rise of the American high school

Secondary education. Once the common school was solidly entrenched, the scant opportunity afforded the lower classes for more than a rudimentary education fell under increasing challenge. If it was right to order children to learn reading, writing, and arithmetic and to offer them free tax-supported schooling, some reasoned, then it was also right to accommodate those desiring advanced instruction. Before long, a few common schools, yielding to parental insistence, introduced courses beyond the elementary level. Such was the germ of the high school in the U.S.

The first high school in the United States opened in Boston in 1821 as the English Classical School, a designation that soon was changed to English High School. Designed for the sons of the "mercantile and mechanic classes," it provided three years of free instruction in English, mathematics, surveying, navigation, geography, history, logic, ethics, and civics. In 1825 New York City inaugurated the first high school outside New England. The next year Boston braved free secondary education for girls, judiciously diluted and restricted to 130. When the number of applicants vastly exceeded this figure, the city fathers abandoned the project.

The high-school movement was spurred less by these diffuse developments than by legislation by Massachusetts in 1827 that ordered towns of 500 families to furnish public instruction in American history, algebra, geometry, and bookkeeping, in addition to the common primary subjects. Furthermore, towns of 4,000 were to offer courses in history, logic, rhetoric, Latin, and Greek. The measure lacked public backing, but it set the guideposts for similar legislation elsewhere. The contention that government had no right to finance high schools remained an issue until the 1870s, when Michigan's supreme court, finding for the city of Kalamazoo in litigation brought by a taxpayer, declared the high school to be a necessary part of the state's system of public instruction.

Education for females. Though the common school vouchsafed instruction to girls, girls' chances to attend high school—not to say college—were slight. The "female academies," attended mainly by daughters of the middle class, were not numerous, and they varied in their emphases, often stressing social or domestic subjects. The truth is that as late as the 1840s, when the lowliest man could vote and hold office, women were haltered by taboos of every sort. But as America advanced industrially, and more and more women flocked to the mill and the office, their desire for greater educational opportunity grew. As in the struggle for the common school, the cause of women's education bred leaders, many of whom founded schools and communicated internationally. In 1833 Oberlin College in Ohio hazarded coeducation, and 20 years later Antioch College, also in Ohio, followed suit. Beyond the Mississippi every state university, except that of Missouri, was coeducational from its beginning. The East moved more warily; Cornell University was the first Eastern school to become coeducational, in 1872.

Co-education

Higher education. While women were crusading for greater educational opportunity, the college itself was undergoing alteration. It had begun as a cradle of divinity, but, as the 18th century waned, it was displaying a mounting secularity. In the course of the 19th century, not only did colleges surge in number, but some of the more enterprising of them undertook to reshape their purpose. Soon after its opening in 1885, Bryn Mawr College in Pennsylvania announced courses for the master's and doctor's degrees. Inspired by the scholarly accomplishments of German universities, Johns Hopkins University in Baltimore, founded in 1867, put its weight on research. Twenty years later Clark University in Massachusetts opened as a purely graduate school. Soon the graduate trend invaded older schools as well.

The early normal schools, or teacher-training schools, were primitive; often they were merely higher elementary schools, rehearsing their students for a year in basic reading and arithmetic, rectitude and piety, some history, mathematics, and physiology, and, if they survived, a rudimentary pedagogy. After the 1860s the ideas and experiments of Pestalozzi and Froebel combined with widespread social-democratic influences on education and advances in psychological thought to change schooling. This confluence, which was most noticeable in elementary education, resulted in the appearance of the kindergarten and in methods proceeding from the nature of the child and including content representing more of the present society. While much of the rationale was religious or mystical, the outcome was socially and psychologically more realistic. Since the early phases of schooling were initially the only concern of teacher training, it was natural that the idea of preparing teachers to use techniques derived from the new concepts, including the greater systematization introduced by Herbart, and the necessity for teachers to learn specifically about the child would substantially augment teacher-training programs and lay the groundwork for immense institutional expansion in the first half of the 20th century.

(A.E.M./R.F.L.)

The British dominions. *Canada.* In the early period of the 19th century, until about 1840, schooling in Canada was much the same as it was in England; it was provided through the efforts of religious and philanthropic organizations and dominated by the Church of England. Although there was overlap among types of schools (identified historically), there are records of parish schools, charity schools, Sunday schools, and monitorial schools for the common people. The instructional fare was a rudimentary combination of religious instruction and literacy skills, perhaps supplemented by some practical work.

More advanced education was limited to the upper social classes and was given in Latin grammar schools or in private schools with various curricular extensions on the classical base. Academies, largely supported by the middle class of nonconformist groups, presented a broad curriculum of liberal arts that spanned the secondary and higher levels of education. In general, instruction relied on a simple chain concept of "transmission-absorption-mental storage," which was kept going by direct application of reward or punishment.

In the middle period, which lasted to about 1870, public systems of education emerged, accommodating religious interests in a state framework. Public support was won

for the common school, leading toward universal elementary education. Secondary and higher education began to assume a public character. The principle of local responsibility under central provincial authority was elaborated in the respective provinces.

Church and state relations in Canada

Of central importance in the development of Canadian education is the kind of agreement reached on church–state relations in education during this period. At one extreme is the arrangement made in Newfoundland from 1836 to accommodate all numerically represented denominations separately within a loose system (not until 1920 was a unified system of education developed, which still works through five denominational subsystems); at the other extreme are the arrangements made in British Columbia, which became decisive when it entered the Canadian Confederation, to establish and maintain a free, unified, centralized nonsectarian system. Other provinces eventually developed patterns that represented compromises. The Nova Scotia–New Brunswick pattern, for instance, provided a unified system that in principle was nonsectarian but that allowed the grouping of Roman Catholic children for education, thus legalizing sectarian schools within the system. Ontario placed separate Catholic schools within a unified school system. Québec supported a dual confessional system from the 1840s to the 1960s, with parallel structures for Roman Catholic and Protestant schooling at both the local and provincial levels. Manitoba adopted Québec's dual confessional system in 1871, then changed to a unified, centralized nonsectarian system amid much controversy in 1896.

The British North America Act of 1867, Canada's constitution, lodged authority for education in the provinces, at the same time guaranteeing denominational rights (in the "minority-school protective clause") if such rights existed by law at the time of entry into confederation. These two provisions established the pluralistic nature of Canadian education, and the union of the provinces and the entrance of western provinces gave Canada, by 1880, a national base on which to build the Canadian institution of education.

The final years of the 19th century were years of structural formalization of the educational foundations developed in the productive middle period. In this, Ontario's leadership was evident, especially as it affected the model of education evolving in the western territories. After Alberta and Saskatchewan were admitted as provinces in 1905, some divergence from Ontario took place: notably, both provinces required that Roman Catholic taxes go to separate Catholic schools (the decision in Ontario was based on free choice), and Alberta allowed separate school privileges through the secondary level. (Saskatchewan extended full funding of Roman Catholic separate schools to the end of high school in the early 1960s, Ontario in the late 1980s).

Toward the end of the 19th century, elementary schooling, by then established, was becoming compulsory. The cost of secondary education was diminishing, and the distinction in level and curriculum between the secondary and the elementary school was sharpened in the system of public schools. Communities were responsible for maintaining schools through a combination of local taxes and provincial grants, while provincial departments standardized the conduct of schooling through inspections, examinations, and prescription of course content and materials.

Changes in instructional theory, taking place during the latter part of the 19th century throughout the Western world, revolutionized the classroom. One major shift was from the imposition of knowledge on the mind of the learner to an emphasis on the learner's activity of perception and comprehension of knowledge. The impact of science on the higher-school curriculum was matched by its impact on educational theory and, consequently, on teacher training. Both scientific disciplines (such as educational psychology) and scientific methods of teaching became necessary to the training of teachers who were to operate in a new setting of teacher–pupil and subject-matter relations.

Australia. The development of Australian education through the 19th century was affected by a pervasive British influence, by a continuous economic struggle against harsh environmental conditions, and by the tendency for population to be concentrated in centres that accrued and extended political authority over the region. The particular historical thread around which educational developments took place was the question of denominational schools.

Church and state relations in Australia

From the first immigrant landing in 1788 through the early decades of the 19th century, education was provided on an occasional and rather haphazard basis, by the most expedient means available. In general, the assumption and the practice was that schooling would be provided by the church or by church organizations, such as the SPGFP, and colonial governments made small grants to aid such provision. It was also assumed that the Church of England would dominate the religious-educational scene, and a Church and School Corporation was set up in 1826 to administer endowments for Church of England efforts. Even at this early stage, however, the resistance of Nonconformists, especially Presbyterians and Roman Catholics, shortly defeated the attempt to "establish" Church of England institutions. The only early organized attempt at mass education was through monitorial systems.

In 1833 the governor of New South Wales asserted government responsibility for education by proposing the introduction of a nondenominational system that would reduce religion in schools to reading commonly approved scriptures and to providing release time for sectarian instruction by clergymen. The importance of the proposal lay in its spirit of religious compromise and its initiation of state responsibility for education, both of which were predictive of future development.

Because of sectarian resistance, mainly from Anglican and Catholic groups, so-called national schools were introduced alongside denominational schools in 1848 as a dual system, administered by two corresponding boards. Through the middle period of the century, similar sectarian compromises were found in other Australian colonies. The establishment of state systems were, however, seriously impeded by the extremity of the struggle for survival in hostile geographic conditions. In New South Wales a Public Schools Bill was passed in 1866, creating a single Council of Education. State aid to denominational schools was continued but under conditions stipulated by the state.

Victoria became a separate colony in 1850 and was initially fraught with particular problems occasioned by the arrival of a migrant gold-rush population. Little was accomplished in education, other than increased assistance to religious denominations, until 1856. After that the move for a state system gained impetus, and a Common Schools Bill was passed in 1862, establishing a system similar to that accepted in New South Wales. Soon after separation, Queensland's Primary Education Bill was passed in 1860, subordinating denominational schools and reinforcing the principle of common-school development in Australia. South Australia held to a continuous development of a general system based on common Christianity, but Western Australia's Elementary Education Bill of 1871 returned to dual support for both government and voluntary schools.

The support for state educational systems increased during the 1860s and 1870s as an alternative to interdenominational conflict was sought. In this development the Protestants, gradually and sometimes reluctantly, acquiesced. Catholic resistance was never overcome, and the consequent evolution of a separate Roman Catholic school system did not diminish Catholic dissatisfaction with the movement to state schools. The dilemma of Catholic citizens with regard to nonsectarian public education was universal: as citizens they were financially obligated for the public schools; as Roman Catholics they were committed to education in schools of their own faith.

The intention to educate all children and to raise the quality of instruction in common schools required governmental actions that could transform voluntary, exclusive, uneven provisions into uniform public standards. In Australia, particular motivating factors were the dramatic increases in population and economic growth and the recognized inadequacy of existing schools. The establishment

of secular public-school systems under government control was made unequivocal through the passage of legislation between 1872 and 1895. These bills did not abolish general Christian instruction, nor did they generally refuse release time for sectarian instruction. They did disallow sectarian claims for financial support and for a place in public education. The decision was for the operation of schools for all children, undertaken by the one agency that could act on behalf of the whole society, the government.

New Zealand. In New Zealand's early colonial period, between 1840 and 1852, certain provisions were made for endowments for religious and educational purposes, but education was considered, in accordance with prevailing views in England, a private or voluntary matter. Corresponding to general social distinctions, academic education was relegated to denominational, fee-charging schools, and common education was provided as a charitable service. Religious preference was avoided as much as possible, with the aim of minimizing sectarian conflict.

Church and state relations in New Zealand

Secular opposition to religious bias, even on a pluralistic basis, was, however, already evident. In 1852 New Zealand was granted self-government under the Constitution Act, and responsibility for education was placed in the councils of the six provinces. Although each province acted independently and somewhat according to the traditions of the dominant cultural group, the general sentiment moved in the next 20 years toward the establishment of public school systems. By 1876, when the provincial governments were abolished, the people of New Zealand, through varying regional decisions, had accepted governmental responsibility for education, had opted for nonsectarian schools, and had started on the path to free, compulsory common schooling.

The basic national legislation was passed in 1877. The Education Act provided for public elementary education that would be secular, free to age 15, and compulsory to age 13. Because of enforcement difficulties and legal exceptions, the compulsory clause was rather loose, but it instituted the rule. It was strengthened between 1885 and 1898, and high-school enrollments increased steadily after 1911. The act of 1877 also revised the administrative structure under a national ministerial Department of Education. Initially, the central department was little more than a funding source, while critical control was vested in regional boards elected by local school committees. In the competitive struggle between the department and the regional boards that waxed and waned well into the 20th century, neither gained the exclusive dominance sometimes sought. The primary position of the central authority in educational administration was confirmed in the reform period between 1899 and 1914, however, when control of inspectors, effective control of primary teacher appointment and promotion, and stipulative control in fund granting went to the Department of Education. These developments, together with curriculum and examination reforms, marked a new beginning in New Zealand education. (R.F.L.)

THE SPREAD OF WESTERN EDUCATIONAL PRACTICES TO ASIAN COUNTRIES

India. Originally the British went to India as tradesmen, but gradually they became the rulers of the country. On Dec. 31, 1600, the East India Company was established, and, like all commercial bodies, its main objective was trade. Gradually during the 18th century the pendulum swung from commerce to administration; the deterioration of Mughal power in India, the final expulsion of French rivals in the Seven Years' War, and the virtual appropriation of Bengal and Bihār in a treaty of 1765 had all made the company a ruling power. In spite of this, the company did not recognize the promotion of education among the natives of India as a part of its duty or obligation. For a long time the British at home were greatly opposed to any system of public instruction for the Indians, as they were for their own people.

Education under the East India Company

The feelings of the public authorities in England were first tested in the year 1793, when William Wilberforce, the famous British philanthropist, proposed to add two clauses to the company's charter act of that year for sending out schoolmasters to India. This encountered the greatest opposition in the council of directors, and it was found necessary to withdraw the clauses. For 20 years thereafter, the ruling authorities in England refused to accept responsibility for the education of Indian people. It was only in 1813, when the company's charter was renewed, that a clause was inserted requiring the governor-general to devote not less than 100,000 rupees annually to the education of Indians.

Some organization was required in order to disburse the educational grant. A General Committee of Public Instruction, constituted in Calcutta in 1823, started its work with an Orientalist policy, rather than a Western-oriented one, since the majority of the members were Orientalists. The money available was spent mainly on the teaching of Sanskrit and Arabic and on the translation of English works into these languages. Some encouragement was also given to the production of books in English.

Meanwhile, a new impetus was given to education from two sources of different character. One was from the Christian missionaries and the other from a "semirationalist" movement. The Christian missionaries had started their educational activities as early as 1542, upon the arrival of St. Francis Xavier. Afterward the movement spread throughout the land and exercised a lasting influence on Indian education. It gave a new direction to elementary education through the introduction of instruction at regular and fixed hours, a broad curriculum, and a clear-cut class system. By printing books in different vernaculars, the missionaries stimulated the development of Indian languages. But hand in hand with the study of the vernaculars went the teaching of Western subjects through the medium of English, called in India "English education."

Besides the missionaries, there were men in Bengal who, though admitting the value of Oriental learning for the advancement of civilization, thought that better things could be achieved through the so-called English education. In 1817 these semirationalists, led by Rām Mohan Roy, the celebrated Indian reformer, founded the Hindu College in Calcutta, the alumni of which established a large number of English schools all over Bengal. The demand for English education in Bengal thus preceded by 20 years any government action in that direction.

In the meantime the influence of the Orientalists was waning in the General Committee, as younger members with more radical views joined it. They challenged the policy of patronizing Oriental learning and advocated the need for spreading Western knowledge through the medium of English. Thus arose the controversy as to whether educational grants should be used to promote Oriental learning or Western knowledge. The controversy between the Orientalists and the Anglicists was decided in favour of the latter by the famous Minute on Education of 1835 submitted by Thomas Babington Macaulay, the legal member of the governor-general's executive council. His recommendations were accepted by Lord William Bentinck, the governor-general. The decision was announced on March 7, 1835, in a brief resolution that determined the character of higher education in India for the ensuing century. Although the schools for Oriental learning were maintained for some years, the translation of English books into Sanskrit and Arabic was immediately discontinued. Thus the system of "English education" was adopted by the government. It should be noted, however, that primary education did not attract any attention at all.

Orientalists versus Anglicists

Bentinck's resolution was followed by other enactments accelerating the growth of English education in India. The first was the Freedom of Press Act (1835), which encouraged the printing and publication of books and made English books available at low cost. Two years later, Persian was abolished as the language of record and the courts (to the dismay of the Muslims) and was replaced by English and Indian languages in higher and lower courts, respectively. Finally, Lord Hardinge, as governor-general, issued a resolution on Oct. 10, 1844, declaring that for all government appointments preference would be given to the knowledge of English. These measures strengthened the position of English in India, and the lingering prejudices against learning English vanished forever.

Although English education held its ground in Bengal, the Bengal government did not neglect vernacular education altogether. Moreover, in Bombay, Madras, and the North-Western Provinces there was as yet little effective demand for English, and the tendency was to lay the main stress on Indian languages. Bombay adopted the policy of encouraging primary education and spreading Western science and knowledge through the mother tongue. This was done under the able guidance of Mountstuart Elphinstone, then the governor, even though the government also conducted an English school in almost every district in the province. Between 1845 and 1848 a bitter controversy arose regarding the language of instruction, but the issue was between the mother tongue and English, and not between a classical language and English as it was in Bengal. The controversy gathered strength every day; and, in those days of centralization, the matter had to be referred to the Bengal government, which advised the Bombay government to concentrate its attention on English education alone, thus throttling the growth of education through the mother tongue in Bombay. Meanwhile, the Madras government was biding its time, leaving the field of positive effort open to Christian missionaries; as a result of this missionary initiative, English education in the Madras presidency was more extensively imparted than in Bombay.

A laudable experiment in the field of vernacular education was carried out by Lieutenant Governor James Thomason in the North-Western Provinces. Thomason's *ḥalqabandī* system attempted to bring primary education within easy reach of the common people. In each *ḥalqah* (circuit) of villages, a school was established in the most central village so that all the villagers within a radius of two miles might avail themselves of it. For the maintenance of these schools the village landholders agreed to contribute at the rate of 1 percent of their land income. The experiment proved successful, and in 10 years Thomason opened 897 schools and provided elementary education for 23,688 children.

Ḥalqabandī system

The next step in the history of Indian education is marked by Sir Charles Wood's epoch-making Dispatch of 1854, which led to (1) the creation of a separate department for the administration of education in each province, (2) the founding of the universities of Calcutta, Bombay, and Madras in 1857, and (3) the introduction of a system of grants-in-aid. Even when the administration of India passed from the East India Company into the hands of the British crown in 1858, Britain's secretary of state for India confirmed the educational policy of Wood's Dispatch.

The newly established universities did not initially undertake any teaching responsibilities but were merely examining bodies. Their expenses were confined to administration and could be met from the fees paid by the candidates for their degrees and certificates. Although the establishment of the universities did result in a rapid expansion of college education and although the products of the new learning displayed keen scholarship, the value of learning nevertheless soon decayed. In such circumstances it was ironic for the Indian Education Commission of 1882 to declare, "The university degree has become an accepted object of ambition, a passport to distinction in public services and in the learned professions." Another undesirable practice was the domination of the universities over secondary education through their entrance examinations. University policies regarding curricula, examination systems, language of instruction, and other vital problems began to be chalked out by university teachers who had little experience in schoolteaching and who kept the administrative needs and requirements of colleges in the forefront. Thus, secondary schools increasingly prepared their students for a college education and not for life in general.

Excessive emphasis on higher education

The new system also became top-heavy. It must be stated that the commission of 1882 made a very valuable recommendation that the "elementary education of the masses, its provision, extension and improvement requires strenuous efforts of the state in a still larger measure than heretofore." It also desired to check the wild race for academic distinction and "to divert some part of the rapidly swelling stream of students into channels of a more practical character." Despite this warning, however, alternative courses in commerce, agriculture, and technical subjects that were offered in a limited number of selected schools did not prove popular. The educated classes could not be diverted from their conventional path.

In a general view of education during the last two decades of the 19th century, drift was more apparent than government resolve. Elementary education was starved and undernourished, and secondary education was suffering from want of proper supervision. There was an unplanned growth of high schools and colleges since the Education Commission had given a free charter to private enterprise. Many of these private institutions were "coaching institutions rather than places of learning." The universities had no control over them, and state control was negligible because the government had adopted a laissez-faire policy.

The second half of the 19th century is, nonetheless, of great significance to the country because modern India may indeed be said to be a creation of this period. It brought about a renaissance by breaking down geographic barriers and bringing different regions and long-separated Indian communities into close contact with one another. The blind admiration for Western culture was gradually passing away, and a new vision and reorientation in thought were coming about. A feeling of dissatisfaction also developed toward the existing governmental and missionary institutions. It was felt by some of the Indian patriots that the character of Indian youths could be built by Indians themselves. This led to the establishment of a few notable institutions aiming at imparting sound education to Indian youth on national lines—institutions such as the Anglo-Mohammedan Oriental College in Aligarh (1875), the D.A.V. College in Lahore (1886), and the Central Hindu College in Vārānasi (1898). The politically minded classes of the country had also come to regard education as a national need. They were critical of the government's educational policy and resented any innovation that might restrain the pace of educational advance or diminish liberty. (S.N.M.)

Japan. *The Meiji Restoration and the assimilation of Western civilization.* In 1867 the Tokugawa (Edo) shogunate, a dynasty of military rulers established in 1603, was overthrown and the imperial authority of the Meiji dynasty was restored, leading to drastic reforms of the social system. This process has been called the Meiji Restoration, and it ushered in the establishment of a politically unified and modernized state.

In the following generation Japan quickly adopted useful aspects of Western industry and culture to enhance rapid modernization. But Japan's audacious modernization would have been impossible without the enduring peace and cultural achievements of the Tokugawa era. It had boasted a high level of Oriental civilization, especially centring on Confucianism, Shintōism, and Buddhism. The ruling samurai had studied literature and Confucianism at their *hankō* (domain schools); the commoners had learned reading, writing, and arithmetic at numerous *terakoya* (temple schools). Both samurai and commoners also pursued medicine, military science, and practical arts at *shijuku* (private schools). Some of these schools had developed a fairly high level of instruction in Western science and technology by the time of the Meiji Restoration. This cultural heritage helped equip Japan with a formidable potential for rapid Westernization. Indeed, some elements of Western civilization had been gradually introduced into Japan even during the Tokugawa era. The shogunate, notwithstanding its isolationist policy, permitted trade with the Dutch, who conveyed modern Western sciences and arts to Japan. After 1853, moreover, Japan opened its door equally to other Western countries, a result of pressures exerted by the United States Navy under Admiral Matthew C. Perry. Thenceforth, even before the Meiji Restoration, Japanese interest in foreign languages became intense and diverse.

The Tokugawa heritage

Western studies, especially English-language studies, became increasingly popular after the Restoration, and Western culture flooded into Japan. The Meiji government dispatched study commissions and students to Europe and to the United States, and the so-called Westernizers

defeated the conservatives who tried in vain to maintain allegiance to traditional learning.

Establishment of a national system of education. In 1871 Japan's first Ministry of Education was established to develop a national system of education. Ōki Takatō, the secretary of education, foresaw the necessity of establishing schools throughout the nation to develop national wealth, strength, and order, and he outlined a strategy for acquiring the best features of Western education. He assigned commissioners, many of whom were students of Western learning, to design the school system, and in 1872 the Gakusei, or Education System Order, was promulgated. It was the first comprehensive national plan to offer schooling nationwide, according to which the nation was divided into eight university districts, which were further divided into 32 middle-school districts, each accommodating 210 primary-school districts. Unlike the class-based schooling offered during the Tokugawa period, the Gakusei envisioned a unified, egalitarian system of modern national education, designed on a ladder plan. Although the district system was said to have been borrowed from France, the new Japanese education was based on the study of Western education in general and incorporated elements of educational practice in all advanced countries. Curricula and methods of education, for instance, were drawn primarily from the United States.

Gakusei, or Education System Order

This ambitious modern plan for a national education system fell short of full realization, however, because of the lack of sufficient financial support, facilities and equipment, proper teaching materials, and able teachers. Nevertheless, the plan represented an unprecedented historic stage in Japanese educational development. Under the Gakusei system, the Ministry of Education, together with local officials, managed with difficulty to set up elementary schools for children aged six to 14. In 1875 the 24,000 elementary schools had 45,000 teachers and 1,928,000 pupils. This was achieved by gradually reorganizing *terakoya* in many areas into modern schools. The enrollment rate reached only 35 percent of all eligible children, however, and no university was erected at all.

The work of educators and teachers from abroad

In 1873 David Murray, a professor from the United States, was invited to Japan as an adviser to the Ministry of Education; another, Marion M. Scott, assumed direction of teacher training and introduced American methods and curricula at the first normal school in Tokyo, established under the direct control of the ministry. Graduates of the normal school played an important role in disseminating teacher training to other parts of the country. By 1874 the government had set up six normal schools, including one for women. The normal school designed curricula for the primary schools, modeled after those of the United States, and introduced textbooks and methods that spread gradually into the elementary schools of many regions.

The conservative reaction. Following the repression of the Satsuma Rebellion, a samurai uprising in 1877, Japan again forged ahead toward political unity, but there was an increasing trend of antigovernment protest from below, which was epitomized by the Movement for People's Rights. Because of the Satsuma Rebellion, the government was in heavy financial difficulties. Also, with the people's inclination toward Western ideas fading away, a conservative reaction began to emerge, calling for a revival of the Confucian and Shintō legacies and a return to local control of education as practiced in the pre-Restoration era.

Discontent had been mounting among the rural people against the Education System Order of 1872, mainly because it had imposed upon them the financial burdens of establishing schools and yet had not lived up to expectations. Another cause of dissatisfaction was a sense of irrelevance that Japanese attributed to schooling largely based on Western models. The curriculum developed according to the 1872 order was perceived to have little relation to the social and cultural needs of that day, and ordinary Japanese continued to favour the traditional schooling of the *terakoya.* Tanaka Fujimaro, then deputy secretary of education, just returning from an inspection tour in the United States, insisted that the government transfer its authority over education to the local governments, as in the United States, to reflect local needs in schooling. Thus, in 1879 the government nullified the Gakusei and put into force the Kyōikurei, or Education Order, which made for rather less centralization. Not only did the new law abolish the district system that had divided the country into districts, it also reduced central control over school administration, including the power to establish schools and regulate attendance. The Kyōikurei was intended to encourage local initiatives. Such a drastic reform to decentralize education, however, led to an immediate deterioration of schooling and a decline in attendance in some localities; criticism arose among those prefectural governors who had been striving to enforce the Gakusei in their regions.

As a countermeasure, the government introduced a new education order in 1880 calling for a centralization of authority by increasing the powers of the secretary of education and the prefectural governor. Thereafter, the prefecture would provide regulations within the limits of criteria set by the Ministry of Education; some measure of educational unity was thus reached on the prefectural level, and the school system received some needed adjustment. Yet, because of economic stagnation, school attendance remained low.

Reemphasis on Confucian and Shintōist values

Conservatism in education gained crucial support when the Kyōgaku Seishi, or the Imperial Will on the Great Principles of Education, was drafted by Motoda Nagazane, a lecturer attached to the Imperial House in 1870. It stressed the strengthening of traditional morality and virtue to provide a firm base for the emperor. Thereafter, the government began to base its educational policy on the Kyōgaku Seishi with emphasis on Confucian and Shintōist values. In the elementary schools, *shūshin* (national moral education) was made the all-important core of the curricula, and the ministry compiled a textbook with overtones of Confucian morality.

Establishment of nationalistic education systems. With the installation of the cabinet system in 1885, the government made further efforts to pave the way for a modern state. The promulgation of the Meiji constitution, the constitution of the empire of Japan, in 1889 established a balance of imperial power and parliamentary forms. The new minister of education, Mori Arinori, acted as a central figure in enforcing a nationalistic educational policy and worked out a vast revision of the school system. This set a foundation for the nationalistic educational system that developed during the following period in Japan. Japanese education thereafter, in the Prussian manner, tended to be autocratic.

Based on policies advocated by Mori, a series of new acts and orders were promulgated one after another. The first was the Imperial University Order of 1886, which rendered the university a servant of the state for the training of high officials and elites in various fields. Later that year orders concerning the elementary school, the middle school, and the normal school were issued, forming the structural core of the pre-World War II education system. The ministry carried out sweeping revisions of the normal-school system, establishing it as a completely independent track, quite distinct from other educational training. It was marked by a rigid, regimented curriculum designed to foster "a good and obedient, faithful, and respectful character." As a result of these reforms the rate of attendance at the four-year compulsory education level reached 81 percent by 1900.

Together with these reforms, the Imperial Rescript on Education (Kyōiku Chokugo) of 1890 played a major role in providing a structure for national morality. By reemphasizing the traditional Confucian and Shintō values and redefining the courses in *shūshin,* it was to place morality and education on a foundation of imperial authority. It would provide the guiding principle for Japan's education until the end of World War II.

Promotion of industrial education. Ever since the Meiji Restoration in 1868, the national target had been *fukoku-kyōhei* ("wealth accumulation and military strength") and industrialization. From the outset the Meiji government had been busy introducing science and technology from Europe and America but nevertheless had difficulties in realizing such goals.

Inoue Kowashi, who became minister of education in 1893, was convinced that modern industries would be the most vital element in the future development of Japan and thus gave priority to industrial and vocational education. In 1894 the Subsidy Act for Technical Education was published, followed by the Technical Teachers' Training Regulations and the Apprentice School Regulations. The system of industrial education was in general consolidated and integrated. These measures contributed to the training of many of the human resources required for the subsequent development of modern industry in Japan.

(A.Na./N.S.)

Education in the 20th century

SOCIAL AND HISTORICAL BACKGROUND

International wars, together with an intensification of internal stresses and conflicts among social, racial, and ideological groups, characterized the 20th century and have had profound effects on education. Rapidly spreading prosperity but widening gaps between rich and poor, immense increases in world population but a declining birth rate in Western countries, the growth of large-scale industry and its dependence on science and technological advancement, the increasing power of both organized labour and international business, and the enormous influence of both technical and sociopsychological advances in communication, especially as utilized in mass media, are changes that have had far-reaching effects. Challenges to accepted values, including those supported by religion; changes in social relations, especially toward versions of group and individual equality; and an explosion of knowledge affecting paradigms as well as particular information mark a century of social and political swings, always toward a more dynamic and less categorical resolution. The institutional means of handling this uncertain world have been to accept more diversity while maintaining basic forms and to rely on management efficiency to ensure practical outcomes.

As new independent nations emerged in Africa and Asia and the needs and powers of the nonaligned nations caused a shift in international thinking, education was seen to be both an instrument of national development and a means of crossing national and cultural barriers. One consequence of this has been a great increase in the quantity of education provided. Attempts have been made to eradicate illiteracy, and colleges and schools have been built everywhere.

The growing affluence of masses of the population in high-income areas in North America and Europe brought about, particularly since World War II, a tremendous demand for secondary and higher education. Most children stay at school until 16, 17, or even 18 years of age, and a substantial fraction spend at least two years at college. The number of universities in many countries doubled or trebled between 1950 and 1970, and opportunities for lifelong learning were extended in all countries.

Demands of industry for technical and continuing education

This growth is sustained partly by the industrial requirements of modern scientific technology. New methods, processes, and machines are continually introduced. Old skills become irrelevant; new industries spring up. In addition, the amount of scientific, as distinct from merely technical, knowledge grows continually. More and more researchers, skilled workers, and high-level professionals are called for. The processing of information has undergone revolutionary change. The educational response has mainly been to develop technical colleges, to promote adult education at all levels, to turn attention to part-time and evening courses, and to provide more training and education within the industrial enterprises themselves.

The adoption of modern methods of food production has diminished the need for agricultural workers, who have headed for the cities. Urbanization, however, brings problems: city centres decay, and there is a trend toward violence. The poorest remain in these centres, and it becomes difficult to provide adequate education. The radical change to large numbers of disrupted families, where the norm is a single working parent, affects the urban poor extensively but in all cases raises an expectation of additional school services. Differences in family background, together with the cultural mix partly occasioned by change of immigration patterns, requires teaching behaviour and content appropriate to a more heterogeneous school population.

MAJOR INTELLECTUAL MOVEMENTS

Influence of psychology and other fields on education. The attempt to apply scientific method to the study of education dates back to the German philosopher Johann Friedrich Herbart, who called for the application of psychology to the art of teaching. But not until the end of the 19th century, when the German psychologist Wilhelm Max Wundt established the first psychological laboratory at the University of Leipzig in 1879, were serious efforts made to separate psychology from philosophy. Wundt's monumental *Principles of Physiological Psychology* (1874) had significant effects on education in the 20th century.

Influence of William James

William James, often considered the father of American psychology of education, began about 1874 to lay the groundwork for his psychophysiological laboratory, which was founded officially at Harvard in 1891. In 1878 he established the first course in psychology in the United States, and in 1890 he published his famous *The Principles of Psychology,* in which he argued that a child's mind is that aspect of his being that enables him to adapt to the world and that the purpose of education is to organize the child's powers of conduct so as to fit him to his social and physical environment. Interests must be awakened and broadened as the natural starting points of instruction. James's *Principles* and *Talks to Teachers on Psychology* cast aside the older notions of psychology in favour of an essentially behaviourist outlook; they asked the teacher to help educate heroic individuals who would project daring visions of the future and work courageously to realize them.

James's student Edward L. Thorndike is credited with the introduction of modern educational psychology, with the publication of *Educational Psychology* in 1903. Thorndike attempted to apply the methods of exact science to the practice of psychology. James and Thorndike, together with the American philosopher John Dewey, cleared away many of the nonempirical claims once made about the steps involved in the development of mental functions from birth to maturity. Another of James's students, G.S. Hall, earned the first Ph.D. in psychology.

Interest in the work of Sigmund Freud and the psychoanalytic image of the child in the 1920s, as well as attempts to apply psychology to national training and education tasks in the 1940s and '50s, stimulated the development of educational psychology, now recognized as a major source for educational theory. Eminent researchers in the field have advanced knowledge of behaviour modification, child development, and motivation. They have studied learning theories ranging from classical and instrumental conditioning and technical models to social theories and open humanistic varieties. Besides the specific applications of measurement, counseling, and clinical psychology, psychology has contributed to education through studies of cognition, information processing, instructional technology, and learning styles. After much controversy about nature versus nurture and about qualitative versus quantitative methods, Jungian, phenomenological, and ethnographic methods have taken their place alongside psychobiological explanations to help educationists understand the place of heredity, general environment, and school in development and learning.

The relationship between educational history and other fields of study has become increasingly close. Social science may be used to study interactions and speech to discover what is actually happening in a classroom. Philosophy of science has led educational theorists to attempt to understand paradigmatic shifts in knowledge. The critical literature of the 1960s and '70s attacked all institutions as conveyors of the motives and economic interests of the dominant class. Both social philosophy and critical sociology have continued to elaborate the themes of social control and oppression as embedded in educational institutions. In a world of social as well as intellectual change, there were necessarily new ethical questions, such as those dealing with abortion, biological experimentation,

and child rights, which placed new demands on education and required new methods of teaching.

Traditional movements. George Spindler's work in educational anthropology led to new conceptions of educational theory in the mid-20th century. Research in cognitive science and feminist scholarship contributed other emphases starting in the 1970s. Against these and other "progressive" lines of 20th-century education, there have been strong voices advocating older traditions. These voices were particularly strong in the 1930s, in the 1950s, and again in the 1980s. Essentialists stress those human experiences that they believe are indispensable to people living today or at any time. They favour the "mental disciplines" and, in the matter of method and content, put effort above interest, subjects above activities, collective experience above that of the individual, logical organization above the psychological, and the teacher's initiative above that of the learner.

Essentialist, liberal, and religious education

Closely related to essentialism is humanistic, or liberal, education. Robert M. Hutchins, president and then chancellor of the University of Chicago from 1929 to 1951, and Mortimer J. Adler, professor of the philosophy of law at the same institution, were its most recognized proponents. Adler argued for the restoration of an Aristotelian viewpoint in education. Maintaining that there are unchanging verities, he sought a return to education fixed in content and aim. Hutchins denounced American higher education for its vocationalism and "anti-intellectualism," as well as for its preoccupation with isolated specialization. He and his colleagues urged a return to the cultivation of the intellect."

Yet another philosophy is that underlying Roman Catholic education. Theocentric in its viewpoint, Catholic scholasticism has God as its unchanging basis of action. It insists that without such a basis there can be no real aim to any type of living, and hence there can be no real purpose in any system of education. The church's

> whole educational aim is to restore the sons of Adam to their high position as children of God. [It insists that] education must prepare man for what he should do here below in order to attain the sublime end for which he was created. (From Pius XI, encyclical on the "Christian Education of Youth," Dec. 31, 1929.)

According to this view, everything in education—content, method, discipline—must lead in the direction of man's supernatural destiny.

New foundations. The three concerns that guided the development of 20th-century education were the child, science, and society. The foundations for this trilogy were laid by so-called progressive education movements supporting child-centred education, scientific-realist education, and social reconstruction.

Progressive education. The progressive education movement was part and parcel of a broader social and political reform called the Progressive movement, which dates to the last decades of the 19th century and the early decades of the 20th. Elementary education had spread throughout the Western world, largely doing away with illiteracy and raising the level of social understanding. Yet, despite this progress, the schools had failed to keep pace with the tremendous social changes that had been going on.

Dissatisfaction with existing schools led several American educational reformers to establish experimental schools during the last decade of the 19th century and in the early 20th century. The principal experimental schools in the United States up to 1914 were the University of Chicago Laboratory School, founded in 1896 and directed by John Dewey; the Francis W. Parker School, founded in 1901 in Chicago; the School of Organic Education at Fairhope, Ala., founded by Marietta Johnson in 1907; and the experimental elementary school at the University of Missouri (Columbia), founded in 1904 by Junius L. Meriam. The common goal of all was to break down hard and fast subject-matter lines. Each school adopted an activity program. Each operated on the assumption that education should not be imposed from without but should draw forth the latent possibilities from within the child. And each believed in the democratic concept of individual worth.

Some early experimental schools

Dewey, whose writings and lectures influenced educators throughout the world, laid the foundations of a new philosophy that continues to affect the whole structure of education, particularly at the elementary level. His theories were expounded in *School and Society* (1899), *The Child and the Curriculum* (1902), and *Democracy and Education* (1916). For Dewey, philosophy and education render service to each other. Education becomes the laboratory of philosophy. Society should be interpreted to the child through daily living in the classroom, which acts as a miniature society. Education leads to no final end; it is something continuous, "a reconstruction of accumulated experience," which must be directed toward social efficiency. Education is life, not merely a preparation for life.

The views of John Dewey

The influence of progressive education advanced slowly during the first decades of the 20th century. Nevertheless, a number of progressive schools were established, including the Play School and the Walden School in New York City, the Shady Hill School in Cambridge, Mass., the Elementary School of the University of Iowa, and the Oak Lane Day School in Philadelphia. Helen Parkhurst's Dalton Plan, introduced in 1920 at Dalton, Mass., pioneered individually paced learning of broad topics. Carleton Washburne's Winnetka Plan, instituted in 1919 at Winnetka, Ill., viewed learning as a continuous process guided by the child's own goals and capabilities. The Gary Plan, developed in 1908 at Gary, Ind., by William Wirt, established a "complete school," embracing work, study, and play for all grades on a full-year basis.

The spread of progressive education became more rapid from the 1920s on and was not confined to any particular country. In the United States the Progressive Education Association (PEA) was formed in 1919. The PEA did much to further the cause of progressive education until it ended, as an organization, in 1955. In 1921 Beatrice Ensor and Europe's leading progressives formed the New Education Fellowship, later renamed the World Education Fellowship.

The notions expressed by progressive education have influenced public-school systems everywhere. Some of the movement's lasting effects can be seen in the activity programs, imaginative writing and reading classes, projects linked to the community, flexible classroom space, dramatics and informal activities, discovery methods of learning, self-assessment systems, and programs for the development of citizenship and responsibility found in school systems all over the world.

Child-centred education. Proponents of the child-centred approach to education have typically argued that the school should be fitted to the needs of the child and not the child to the school. These ideas, first explored in Europe, notably in Rousseau's *Émile* (1762) and in Pestalozzi's *How Gertrude Teaches Her Children* (1801), were implemented in American systems by pioneering educators such as Francis W. Parker. Parker became superintendent of schools in Quincy, Mass., in 1875. He assailed the mechanical, assembly-line methods of traditional schools and stressed "quality teaching," by which he meant such things as activity, creative self-expression, excursions, understanding the individual, and the development of personality.

A different approach to child-centred education arose as a result of the study and care of the physically and mentally handicapped. Teachers had to invent their own methods to meet the needs of such children, because the ordinary schools did not supply them. When these methods proved successful with handicapped children, the question arose whether they might not yield even better results with ordinary children. During the first decade of the 20th century, the educationists Maria Montessori of Rome and Ovide Decroly of Brussels both successfully applied their educational inventions in schools for ordinary boys and girls.

The Montessori method's underlying assumption is the child's need to escape from the domination of parent and teacher. According to Montessori, children, who are the unhappy victims of adult suppression, have been compelled to adopt defensive measures foreign to their real nature in the struggle to hold their own. The first move toward the reform of education, therefore, should be directed toward educators: to enlighten their consciences, to remove their perceptions of superiority, and to make them humble and passive in their attitudes toward the young.

The Montessori method

The next move should be to provide a new environment in which the child has a chance to live a life of his own. In the Montessori method, the senses are separately trained by means of apparatuses calculated to enlist spontaneous interest at the successive stages of mental growth. By similar self-educative devices, the child is led to individual mastery of the basic skills of everyday life and then to schoolwork in arithmetic and grammar.

The Decroly method can be characterized as a program of work based on the activities of observation, association, and expression. Educative games are incorporated into the curriculum. Its basic features are "centres of interest" that serve the fundamental needs of the child. These are food, shelter, defense, and work. The principle of giving priority to wholes rather than to parts is emphasized in teaching children to read, write, and count, and care is taken to reach a comprehensive view of the experiences of life.

The Montessori and the Decroly methods have spread throughout the world and have widely influenced attitudes and practices of educating young children.

Pestalozzian principles encouraged the introduction of music education into early childhood programs. Research has shown that music has an undeniable effect on the development of the young child, especially in such areas as movement, temper, and speech and listening patterns. The four most common methods of early childhood music education are those developed by Émile Jaques-Dalcroze, Carl Orff, and Zoltán Kodály and the Comprehensive Musicianship approach. The Dalcroze method emphasizes movement; Orff, dramatization; Kodály, singing games; and Comprehensive Musicianship, exploration and discovery. Another popular method, developed by the Japanese violinist Shinichi Suzuki, is based on the theory that young children learn music in the same way that they learn their first language.

Scientific-realist education. The scientific-realist education movement began in 1900 when Édouard Claparède, then a doctor at the Psychological Laboratory of the University of Geneva, responded to an appeal from the women in charge of special schools for backward and abnormal children in Geneva. The experience brought him to realize some of the defects of ordinary schools. Not as much thought is given, he argued, to the minds of children as is given to their feet. Their shoes are of different sizes and shapes, made to fit their feet. When shall we have schools to measure? The psychological principles needed to adapt education to individual children were expounded in his *Psychologie de l'enfant et pédagogie experimentale* (1909). Later Claparède took a leading part in the creation of the J.-J. Rousseau Institute in Geneva, a school of educational sciences to which came students from all over the world.

Jean Piaget's studies of child development

Theorists such as Claparède hoped to provide a scientific basis for education, an aim that was furthered by the Swiss psychologist Jean Piaget, who studied in a philosophical and psychological manner the intellectual development of children. Piaget argued, on the basis of his observations, that development of intelligence exhibits four chief stages.

The first stage takes place during infancy, when children, even before they learn to speak, put objects together (addition), then separate them (subtraction), perceiving them as collections, rings, networks, groups. By the age of two or three, a basis has been laid. The children have developed kinetic muscular intelligence to some degree—they can think with their fingers, their hands, their bodies. Aided by language, the capacity for symbolic thinking develops. This constitutes the second stage. Up to the age of seven or eight, some of the fundamental categories of adult thinking are still absent: there is seldom any notion, for instance, of cause and effect relationships.

The third stage is that of concrete operation. The child has begun to know how to deal with mental symbols and acquires abstract notions such as "responsibility." But the child operates only when in the presence of concrete objects that can be manipulated. Pure abstract thinking is still too difficult. Teaching at this stage must be exceedingly concrete and active; purely verbal teaching is out of place. Only after about 12 years of age, with the onset of adolescence, do children develop the power to deal with formal mental operations not immediately attached to objects. Only then do theories begin to acquire real significance, and only then can purely verbal teaching be used.

While still influential, Piaget's work on child development has been expanded by cognitive psychologists. Other developmentalists include Lewis Terman (creator of the Stanford-Binet intelligence test) and Arnold Gesell (author of influential books on child rearing).

The child's total development, particularly emotional and social growth, also concerned educational reformers. They pointed out the error in assuming that incentives to mental effort are the same for adults and children. The English philosopher Alfred North Whitehead, in his doctrine of the "Cycle of Interests," posited that romance, precision, and generalization are the stages through which, rhythmically, mental growth proceeds.

> Education should consist in a continual repetition of such cycles. Each lesson in a minor way should form an eddy cycle issuing in its own subordinate process.

Whitehead believed that any scheme of education must be judged by the extent to which it stimulates a child to think. From the beginning of education, children should experience the joy of discovery.

Social-reconstructionist education. Social-reconstructionist education is based on the theory that society can be reconstructed through the complete control of education. The objective is to change society to conform to the basic ideals of the political party or government in power or to create a utopian society through education.

Communist education, probably the most pervasive version of operational social-reconstructionism in the world, is now much less widely practiced since the demise of the Soviet bloc. Originally based on the philosophy of Karl Marx and institutionalized in the Soviet Union, it reached a large proportion of the world's youth. From the 1950s onward, much attention was paid to the ideal of "polytechnization." Man, so the argument runs, is not simply *Homo sapiens* but rather *Homo faber,* the constructor and builder. He attains full mental, moral, and spiritual development through entering into social relations with others, particularly in cooperative efforts to produce material, artistic, and spiritual goods and achievements. The school, according to this theory, should prepare pupils for such productive activities—for instance, by studying and, if possible, sharing in the work done in field, farm, or factory.

Reconstructionist education in Israel

A different social-reconstructionist movement was that of the kibbutzim (collective farms) of Israel. Although the kibbutz movement peaked in the late 20th century, the educational values are still apparent. The most striking feature of kibbutz education is that the parents forgo rearing and educating their offspring themselves and instead hand the children over to professional educators, sometimes immediately after birth. The kibbutz type of education developed for both practical and economic reasons, but gradually educational considerations gained prominence. These were: (1) that the kibbutz way of life makes for complete equality of the sexes, (2) that the education of children in special children's houses is the best way of perpetuating the kibbutz way of life, (3) that collective education is more "scientific" than education within the family, inasmuch as children are reared and trained by experts (*i.e.,* qualified nurses, kindergarten teachers, and other educators), in an atmosphere free of the tensions engendered by family relationships, and (4) that collective education is more democratic than traditional education and more in keeping with the spirit of cooperative living.

MAJOR TRENDS AND PROBLEMS

The idea of social-reconstructionist education rests on a 19th-century belief in the power of education to change society. The idea that schooling can influence either society or the individual is still widely held, affecting the growth of tertiary-level alternatives, management strategies, and education of disadvantaged people, both in industrialized and in developing countries.

The international concern with assistance to people in less-developed countries has been paralleled by the inclusiveness that characterized education in the 20th century. Education has been seen as a primary instrument in recognizing and providing equality for those suffering

Integrative trends

disadvantage because of sex, race, ethnic origin, age, or physical disability. This has required revisions of textbooks, new consciousness about language, and change in criteria for admission to higher levels. It has led to more demanding definitions of equality involving, for example, equality of outcome rather than of opportunity.

The inclusion of all children and youth is part of a general integrative trend that has accelerated since World War II. It relates to some newer developments as well. Concern for the earth's endangered environment has become central, emphasizing in both intellectual and social life the need for cooperation rather than competition, the importance of understanding interrelationships of the ecosystem, and the idea that ecology can be used as an organizing concept. In a different vein, the rapid development of microelectronics, particularly the use of computers for multiple functions in education, goes far beyond possibilities of earlier technological advances. Although technology is thought of by some as antagonistic to humanistic concerns, others argue that it makes communication and comprehension available to a wider population and encourages "system thinking," both ultimately integrative effects.

The polarization of opinion on technology's effects and most other important issues is a problem in educational policy determination. In addition to the difficulties of governing increasingly large and diverse education systems, as well as those of meeting the never-ending demands of expanding education, the chronic lack of consensus makes the system unable to respond satisfactorily to public criticism and unable to plan for substantive long-range development. The political and administrative responses so far have been (1) to attend to short-run efficiency by improving management techniques and (2) to adopt polar responses to accommodate polar criticisms. Thus, community and community schools have been emphasized along with central control and standardization, and institutional alternatives have been opened, while the structure of main institutions has become more articulated. For example, the focus of attention has been placed on the transition stages, which earlier were virtually ignored: from home to school, from primary to secondary to upper secondary, from school to work. Tertiary institutions have been reconceived as part of a unified level; testing has become more sophisticated and credentials have become more differentiated either by certificate or by transcript. Alternative teaching strategies have been encouraged in theory, but basic curriculum uniformity has effectively restricted the practice of new methods. General education is still mainly abstract, and subject matter, though internally more dynamic, still rests on language, mathematics, and science. There has been an increasing reliance on the construction of subject matter to guide the method of teaching. Teachers are entrusted with a greater variety of tasks, but they are less trusted with knowledge, leading political authorities to call for upgrading of teacher training, teacher in-service training, and regular assessment of teacher performance.

Recent reform efforts have been focused on integrating general and vocational education and on encouraging lifelong or recurrent education to meet changing individual and social needs. Thus, not only has the number of students and institutions increased, as a result of inclusion policies, but the scope of education has also expanded. This tremendous growth, however, has raised new questions about the proper functions of the school and the effectiveness for life, work, or intellectual advancement of present programs and means of instruction.

WESTERN PATTERNS OF EDUCATION

The United Kingdom. *Early 19th to early 20th century.* English education has been less consciously nationalist than that of continental European countries, but it has been deeply influenced by social class structure. Traditionally, the English have held that the activity of the government should be restricted to essential matters such as the defense of property and should not interfere in education, which was the concern of family and church. The growth of a national education system throughout the 19th century continued without a clear plan or a national decision. The cornerstone of the modern system was laid by the Elementary Education Act of 1870, which accepted the principle that the establishment of a system of elementary schools should be the responsibility of the state. It did not, however, eliminate the traditional prominence of voluntary agencies in the sphere of English education. Nor did it provide for secondary education, which was conducted largely by voluntary fee-charging grammar schools and "public" schools. These public schools were usually boarding schools charging rather high fees. Their tradition was aristocratic, exclusive, formal, and classical. Their main goal was to develop "leaders" for service in public life. In 1900 one child in 70 could expect to enter a secondary school of some kind. The grammar schools copied the curriculum of the public schools, so that only the intellectual and social elite were able to attend.

The Elementary Education Act of 1870

In 1899 an advance was made toward the development of a national system encompassing both elementary and secondary education by creating a Board of Education as the central authority for education. The Balfour Act of 1902 established a comprehensive system of local government for both secondary and elementary education. It created new local education authorities and empowered them to provide secondary schools and develop technical education. The Education Act of 1918 (The Fisher Act) aimed at the establishment of a "national system of public education available for all persons capable of profiting thereby." Local authorities were called upon to prepare plans for the orderly and progressive development of education. The school-leaving age was raised to 14, and power was given to local authorities to extend it to 15.

Education Act of 1944. The Education Act of 1944 involved a thorough recasting of the educational system. The Board of Education was replaced by a minister who was to direct and control the local education authorities, thereby assuring a more even standard of educational opportunity throughout England and Wales. Every local education authority was required to submit for the minister's approval a development plan for primary and secondary education and a plan for further education in its area. Two central advisory councils were constituted, one for England, another for Wales. These had the power, in addition to dealing with problems set by the minister, to tender advice on their own initiative. The total number of education authorities in England and Wales was reduced from 315 to 146.

The educational systems of Scotland and Northern Ireland are separate and distinct from that of England and Wales, although there are close links between them. The essential features of the Education Act of 1944 of England and Wales were reproduced in the Education Act of 1945 in Scotland and in the Education Act of 1947 in Northern Ireland. There were such adaptations in each country as were required by local traditions and environment.

The complexity of the education system in the United Kingdom arises in part from the pioneer work done in the past by voluntary bodies and a desire to retain the voluntary element in the state system. The act of 1944 continued the religious compromise expressed in the acts of 1870 and 1902 but elaborated and modified it after much consultation with the parties concerned. The act required that, in every state-aided primary and secondary school, the day should begin with collective worship on the part of all pupils and that religious instruction should be given in every such school. As in earlier legislation there was, however, a conscience clause and another to ensure that no teacher should suffer because of religious convictions. Religious instruction continues to be given in both fully maintained and state-aided voluntary schools, and opportunities exist for religious training beyond the daily worship and minimum required instruction. In many schools the religious offering has become nondenominational, and in areas of high non-Christian immigrant population consideration may be given to alternative religious provision.

Structural changes under the 1944 act

Two fundamental reforms in the act of 1944 were the requirement of secondary education for all, a requirement that meant that no school fees could be charged in any school maintained by public authority; and replacement of the former distinction between elementary and higher ed-

ucation by a new classification of "three progressive stages to be known as primary education, secondary education, and further education." To provide an adequate secondary education in accordance with "age, ability, and aptitude," as interpreted by the Ministry of Education, three separate schools were necessary: the grammar school, modeled on elite public schools, the less intellectually rigorous secondary modern school, and the technical school. If, in exceptional circumstances, such provisions were made in a single school, then the school would have to be large enough to comprise the three separate curricula under one roof. Children were directed to the appropriate school at the age of 11 by means of selection tests.

The tripartite system of grammar, secondary modern, and technical schools did not, in fact, flourish. The ministry had never been specific about the proportion of "technically minded" children in the population, but, in terms of school places provided in practice, it was about 5 percent. Since, on the average, grammar-school places were available to 20 percent, this left 75 percent of the child population to be directed to the secondary modern schools, for which the ministry advocated courses not designed to lead to any form of qualification.

The comprehensive movement. Selection procedures at the age of 11 proved to be the Achilles' heel of the grammar school–secondary modern system. Various developments contributed to the downfall of selection at 11: first, the examination successes of the secondary modern schoolchildren; second, the failure of a significant proportion of the children so carefully selected for grammar schools; third, the report of a committee appointed by the British Psychological Society supported arguments that education itself promotes intellectual development and that "intelligence" tests do not in fact measure genetic endowment but rather educational achievement.

The main issue in the 1950s and '60s was whether or not the grammar schools should be retained with selection at 11 plus. One of the main arguments used was that the right of "parental choice" must be upheld. Another was that it was in the "English tradition" to retain a selective system. But gradually the number of comprehensive (nonselective) schools increased.

Policies of Labour and Conservative governments

The Labour Party during the election of 1964 promised to promote the establishment of the comprehensive school and to abolish selection at 11 plus. On taking office, however, the Labour government, instead of legislating, issued a circular in the belief that this would enlist local support and encourage local initiative. The result was conflict between national policy and local policy in some areas. The Conservative government elected in 1970 declared its intention of leaving decisions about reorganization to the local authorities. The comprehensive principle has since become dominant, and the number of comprehensive schools has grown under both Labour and Conservative governments so that most state-maintained secondary schools are now comprehensive. The administrative compromise of leaving organizational options open to local authorities has permitted variations to continue, however. Five to 6 percent of the school population attend completely independent private schools. Enrollment at the exclusively academic, often prestigious, and costly independent secondary schools may be preceded by attendance at private preparatory schools.

The primary school begins at age five and is usually divided into an infant stage (ages five to seven) and a junior stage (ages eight to 11). In those few localities using a middle-school organization, children attend the middle school from age eight or nine to age 13 or 14. Preschool provision is uneven, but a great deal of innovation has taken place in ideas and practices of early-childhood learning. In the infant school, children work together with their teacher. Children may be placed together vertically in the same class, like a family group. Play is considered an activity of central significance in the infant school. It is a vehicle for the child's motivation and learning, carefully structured to promote cognitive development. The teacher's job is to set the environment through organization of space, time, and materials; to encourage, guide, and stimulate; and to see that all children learn and develop independence and responsibility. Studies are interrelated, and the curriculum is flexible.

The compromise regarding school organization is representative of the British educational administration's attempt to balance local and national interests delicately. Local education authorities are responsible for basic school operations, and much of the professional responsibility is passed on to the school. This representation of community and professional interest is underscored in policy documents, such as the 1980 Education Act's stipulation that governing boards include at least two parent and two teacher representatives. Local education authorities maintain a professional administrative staff and administer school finances, which are funded primarily by government grants and local property taxes.

British educational administration

Ultimate authority for education is at the national level, with the Department of Education and Science (formerly the Ministry of Education) headed by the secretary of state for education and science. The department is the agent of governmental policy. It reaches schools through circulars and directives as well as through Her Majesty's Inspectors of Schools. The inspectors advise and report on the general condition of schooling.

Under the Conservative government of Margaret Thatcher emphasis was placed on management efficiency. While decentralization has been applied to operational decisions, the government has nonetheless pushed for standardization of curriculum and streamlining of assessment procedures. Traditionally, curriculum had been decentralized to the extreme in the United Kingdom, being a matter of each teacher's professional judgment, unified only informally (though effectively) through the influence of teacher training, publicized curriculum projects, textbook choices, and public examination syllabi. This resulted in a great deal of curriculum agreement in the common schooling period, narrowing to a secondary core to age 16, including a wide range of options in the comprehensive school, and different basic curricula in selective systems. Independent schools showed some variations, particularly in the requirement of Latin, and the upper secondary stage was characterized by specialization. Through the 1970s and '80s, however, there was central pressure on curriculum improvement in science, practical elements, technical and vocational education, and the relationship of education to economic life. Influential publications have proposed standardization of the curriculum nationally.

Probably the issue that has received the most attention has been the relationship of education to the economy, to industry, and to work. Much of the impact of this attention has been on the post-compulsory sector. Schemes developed outside of the educational establishment provided training for young school-leavers. The Technical and Vocational Education Initiative called for local education authority cooperation with the Manpower Services Commission in the introduction of technical courses that span school and post-school training. Reforms to the examination and certification system exemplify the government's thrust toward improvement of the education–economy link, toward rationalization of the system, and toward coordinated, standardized assessment procedures.

Further education. Further education is officially described as the "post-secondary stage of education, comprising all vocational and nonvocational provision made for young people who have left school, or for adults." Further education thus embraces the vast range of university, technical, commercial, and art education and the wide field of adult education. It is this sector of education, which is concerned with education beyond the normal school-leaving ages of 16 or 18, that has experienced the most astonishing growth in the number of students.

In the 19th century the dominance of Oxford and Cambridge was challenged by the rise of the civic universities, such as London, Manchester, and Birmingham. Following the lead of the 18th-century German universities and responding to a public demand for increased opportunity for higher education, Britain's new civic universities quickly acquired recognition—not only in technological fields but also in the fine and liberal arts.

Many new post-school technical colleges were founded in the early 20th century. The Fisher Act of 1918 empowered the local authorities to levy a rate (tax) to finance such colleges. The universities, on the other hand, received funds from the central government through the University Grants Committee, established in 1911 and reorganized in 1920, after World War I.

A different type of technical college was established in the 1960s—the polytechnic, which provides mainly technological courses of university level as well as courses of a general kind in the arts and sciences. Polytechnics are chartered to award degrees validated by a Council for National Academic Awards.

Thus, the tertiary level in the United Kingdom is made up of colleges of further education, technical colleges, polytechnics, and universities. The colleges offer full-time and part-time courses beyond compulsory-school level. Polytechnics and universities are mainly responsible for degrees and research. The innovative Open University, with its flexible admission policy and study arrangements, opened in 1971. It uses various media to provide highly accessible and flexible higher education for working adults and other part-time students. It serves as an organizational model and provides course materials for similar institutions in other countries.

The Open University

More recent changes in British education have, without changing the basic values in the system, extended education by population, level, and content. New areas for expansion include immigrant cultural groups and multicultural content, the accommodation of special needs, and the development of tools and content in the expanding technology-oriented fields.

Germany. *Imperial Germany.* The formation of the German Empire in 1871 saw the beginning of centralized political control in the country and a corresponding emphasis on state purposes for education. Although liberal and socialist ideas were discussed, and even practiced in experimental schools, the main features of the era were the continued systematization of education, which had progressed in Prussia from 1763, and the class-based division of schools. Education for the great bulk of the population stressed not only literacy but also piety and morality, vocational and economic efficiency, and above all obedience and discipline. The minority of citizens in the upper social and economic strata were educated in separate schools according to a classical humanist rationale of intelligence and fitness that equipped them to fill the higher positions in the Reich. Reform proposals in the last decade of the 19th century led to an overhaul of the education system, but the changes did not remove class privileges.

The *Volksschule*

The *Volksschule* was universal, free, and compulsory. The fundamental subjects were taught along with gymnastics and religion, which held important places in the curriculum. Girls and boys were taught in separate schools except when it was uneconomical to do so. Boys usually received training in manual work, and girls in domestic science. Graduates of the *Volksschule* found it almost impossible to enter the secondary school, which was attended almost exclusively by graduates of private preparatory schools charging fees. The *Volksschule* led its students directly to work and was thus separate and parallel to the secondary-school program rather than sequential.

Boys who, at the age of nine, were about to enter secondary school had to decide on one of the three types of schools, each offering a different curriculum. The traditional classical *Gymnasium* stressed Latin and Greek. The *Realgymnasium* offered a curriculum that was a compromise between the humanities and modern subjects. The *Oberrealschule* stressed modern languages and sciences. Although Kaiser William II threw his influence on the side of the modernists in 1890, the *Gymnasium* continued to overshadow the other two schools until after World War II.

Secondary schools for girls were recognized by Prussia in 1872 and were extended and improved in 1894 and again in 1908. These schools were fee-paying and were thus available chiefly to the upper social and economic strata. The course of instruction lasted 10 years, from six to 16. This 10-year school was called the *Lyzeum*, the first three years being preparatory. Beyond it was the *Oberlyzeum*, which was divided into two courses: the *Frauenschule*, which offered a two-year general course, and the *Lehrerinnenseminar*, which offered a four-year course for prospective elementary-school teachers. Girls who wanted a secondary-school education similar to that of the boys transferred at the age of 13 to the *Studienanstalt*.

Continuation schools for the working class augmented apprenticeship training with part-time education. They were the forerunners of the part-time vocational *Berufsschulen*, which continue today. Greatly influenced by the ideas of Georg Kerschensteiner, these schools increased in importance in the early 20th century. Between 1919 and 1938 they filled out the secondary sector to ensure attendance at some kind of school for all youth to the age of 18.

Weimar Republic. In no sphere of public activity did the establishment of the Weimar Republic after 1919 cause more creative discussion and more far-reaching changes than in that of education. A four-year *Grundschule* was established, free and compulsory for all children. It was the basic building block for all subsequent social liberalization in education. Besides the elementary subjects and religion, the child was instructed in drawing, singing, physical training, and manual work. The *Oberstufe*, the four upper classes of the elementary school, combined with the *Grundschule*, formed a complete whole. Most elementary schools thus provided an eight-year course of study. Intermediate schools (*Mittelschulen*) were established for children who wished a longer and more advanced elementary-school course and were able to pay modest fees.

The Weimar constitution preserved the religious tradition, which had been an essential part of the school curriculum in Germany since the Reformation. No pupil, however, could be compelled to study religion, and no teacher could be forced to teach it. Communities were accorded the right to establish schools in accordance with the particular religious beliefs of the pupils.

Secondary schools in the Weimar period

As regards secondary education, the Weimar Republic kept the prewar division of *Gymnasium*, *Realgymnasium*, and *Oberrealschule*. (There were three comparable schools for girls.) In addition, there was established the *Aufbauschule*, which was a six-year school following completion of the seventh year of the elementary school, and the *Deutsche Oberschule*, a nine-year school that required two modern foreign languages and stressed German culture.

Nazi Germany. After Adolf Hitler's accession to power in 1933, the Nazis set out to reconstruct German society. To do that, the totalitarian government attempted to exert complete control over the populace. Every institution was infused with National Socialist ideology and infiltrated by Nazi personnel in chief positions. Schools were no exception. Even before coming to power, Hitler in *Mein Kampf* had hinted at his plans for broad educational exploitation. The Ministry of Public Enlightenment and Propaganda exercised control over virtually every form of expression—radio, theatre, cinema, the fine arts, the press, churches, and schools. The control of the schools began in March 1933 with the issuing of the first educational decree, which held that "German culture must be treated thoroughly."

The Nazi government attempted to control the minds of the young by incorporating Nazi beliefs into the school curriculum. A major part of biology became "race science," and health education and physical training did not escape the racial stress. Geography became geopolitics, with the study of the fatherland being fundamental. Physical training was made compulsory for all, as was youth labour service. Much of the fundamental curriculum was not disturbed, however.

Changes after World War II. Immediately after World War II the occupying powers (Britain, France, and the United States in the western zones and the Soviet Union in the east) instituted education programs designed to clean out Nazi influence and to reflect their earlier educational values. These efforts were soon absorbed into independent German educational reconstruction. The Basic Law of the Federal Republic of Germany (West Germany) of May 1949 granted autonomy in educational matters to the *Länd* (state) governments. Although efforts to strengthen the federal government's presence waxed and waned,

Länd governments remained independent and were divided along political lines on educational reforms.

Two main political issues dividing the West German states were confessional schooling and the tripartite division of secondary schooling, with conservative states like Bavaria and Baden-Württemberg on the one side and socially progressive states like Hessen and West Berlin on the other. After a 20-year period of reform discussion on these issues, marked by influential state or national proposals, the balance shifted in the mid-1970s to the conservatives, albeit with a great deal of internal liberalization. That is, confessional schools and confessional instruction in schools remained, but the latter increasingly added ecumenical or ethical emphases. This change, like others, has been supported by the presence of a large number of non-German children representing various cultural beliefs and behaviours.

The German school structure

Since the reunification of Germany in 1990, most of the education systems in the former East Germany have been restructured. Across Germany, pupils generally spend four years in the elementary school (*Grundschule*), six years in one of the lower secondary branches, and two years in one of the upper secondary branches. In their four years of attending the *Grundschule,* students receive a basic education in mathematics, German (reading and writing), sciences, humanities, social sciences, and the arts. Although classes are not segmented by learning level or student ability, those children needing extra attention are offered remedial coursework. Long governed by entrance examination, the choice of secondary school is now made by the parents, although performance at the orientation stage, especially in the subjects of German, mathematics, and foreign language (English), influences decisions.

More than one-fourth of secondary-school-age children enter the *Gymnasium,* which, with different academic emphases, remains the successor to its classical ancestor. Education in the *Gymnasium* typically leads to more study at the university level. Perceiving greater opportunity, more parents are choosing a *Gymnasium* education for their children. A decreasing number of students attend the nonselective *Hauptschule* ("main school"), which offers basic subjects to grade nine or 10 and is followed by apprenticeship with part-time vocational school or by full-time vocational school. More than one-fourth attend the *Realschule* (formerly *Mittelschule*), which offers academic and prevocational options. It leads to vocational school or technical school, which in turn leads to commercial, technical, or administrative occupations. Another choice is the *Gesamtschule,* or comprehensive school, which incorporates aspects of the *Gymnasium,* the *Hauptschule,* and the *Realschule.* This approach can lead to vocational education or university study.

The vocational-technical sector has always been given careful government and industry attention, and the network now includes a wide range of methods and content alternatives, with levels up to a university equivalent.

One of the means of coordinating differences between *Länd* systems has been through the Conference of the Cultural Ministers of the states, and one of the important resolutions of this body, in 1973, was for reform of the upper secondary stage. Attention has been given to equalizing opportunities at this stage. This has affected the *Gymnasium* by shifting much of the traditional load to the upper level. Although the first stage is still academically demanding, the foreign-language requirement is much more flexible, and many students now leave for work at the end of the 10th school year. The upper level is required to reach the *Abitur,* qualifying the student for university entrance. Although the range of subjects has been extended, courses have been diversified, and final achievement is now indicated by a cumulative point system. The upper level of the *Gymnasium* is characterized by breadth of knowledge at a high intellectual standard, including cultural essentials as well as an academic concentration.

Whether due to periodic change, German tradition, or inadequate understanding of the reform process, the educational system has returned to basic principles. The incorporation of new alternatives and individual opportunities yields an open rather than a fundamentally changed system. This may be the best way for education to meet the major political themes of modern Germany: individual rights as the criterion of policy determination and the European community as the broader context of national development.

France. *The Third Republic.* The establishment of the Third Republic (1870) brought about the complete renovation of the French schools, in the process of which education became a national enterprise. In 1882 primary education was made compulsory for all children between the ages of six and 13. In 1886, members of the clergy were forbidden to teach in the public schools, and in 1904 the teaching congregations were suppressed. France had thus established a national free, compulsory, and secularized system of elementary schooling. (Although secularization was a necessary government strategy, it was also necessary to permit private Catholic schools, and these have continued to enroll a significant number of French children.)

In spite of the attempt to unify education through national purpose and centralized means, two parallel systems existed, that of the public elementary schools and higher primary schools and that of the selective, overwhelmingly intellectual secondary lycées and their preparatory schools. The lycées emphasized classical studies through the study of Greek and Latin. It was not until 1902 that this exclusive emphasis was challenged by a reform promoting the study of modern languages and science and not until the period between World Wars I and II that education was seen to have a vocational function, other than grossly in a social-class sense, and thus to require democratization.

Centralized administration in French education

The administration of education in France has remained highly centralized and has continued to be concerned with every aspect of national education, including curricula, syllabi, textbooks, and teacher performance. At the head of the system is the minister of national education, who is advised and assisted in the execution of his duties by a hierarchy of officials. The country is divided into 27 educational administrative areas, each known as an "academy." The chief education officer is the rector, the minister's most important representative, who administers the laws and regulations. The inspectorate, represented by regional inspectors under an *inspecteur d'académie* and by national inspectors, has extensive bureaucratic and supervisory powers.

Changes after World War II. Since 1946 education has been included in the plans developed by the central planning commission in France. In general, government has been friendly to educational development and reform. Student protests in the late 1960s and in the 1990s caused an antagonistic reaction, however, and teacher resistance appears to work against many government reform initiatives. Government reform trends in recent years have been toward increasing administrative efficiency and accountability, meeting national economic needs through improved technological education, improving the articulation of system parts, opening the school to the community, and correcting inequalities, through both curricular and organizational provisions. Attention has been given not only to "socializing" the system but also to correcting inequalities that are suffered by French ethnic minorities and immigrant children, to amending social-geographic inequalities, and to increasing options for the handicapped, in both special schools and, after the mid-1970s, regular schools.

The French school structure

In 1947 a commission established to examine the educational system recommended a thorough overhauling of the entire school system. Education was to be compulsory from the age of six to 18. Schooling was to be divided into three successive stages: (1) six to 11, aimed at mastery of the basic skills and knowledge, (2) 11 to 15, a period of guidance to discover aptitudes, and (3) 15 to 18, a stage during which education was to be diversified and specialized. The system has since consistently developed from one featuring a common elementary school to one incorporating a progression into separate paths. Reforms aimed to provide equality of educational experience at each stage and to create curricular conditions that further career advancement without abridging general education or forcing students to choose a profession prematurely.

Preschool education is given in the *école maternelle,* in

which attendance is voluntary from the age of two to six years. Education is compulsory between six and 16 years of age and is free. The five-year elementary school is followed by a four-year lower secondary school, the *collège unique*, which has been the object of much attention. The first two years at the *collège unique* constitute the observation cycle, during which teachers observe student performance; during the remaining two years, the orientation cycle, teachers offer guidance and assist pupils in identifying their abilities and determining a career direction.

At the upper secondary level, from age 15 to 18, students enter either the general and technological high school (*lycée d'enseignement général et technologique*), successor to the traditional academic high school, or the vocational senior high school (*lycée d'enseignement professionel*), encompassing a range of vocational-technical studies and qualifications. Students entering the former choose one of three basic streams the first year, then concentrate the next two years on one of five sections of study: literary-philosophical studies, economics and social science, mathematics and physical science, earth science and biological science, or scientific and industrial technology. The number of sections and particularly the number of technological options is scheduled for expansion. There is a common core of subjects plus electives in grades 10 and 11, but all subjects are oriented to the pupil's major area of study. In grade 12 the subjects are optional. The *baccalauréat* examination taken at the end of these studies qualifies students for university entrance. It consists of written and oral examinations. More than half of the 70 percent who pass are females. The proportion of the age group reaching this peak of school success has risen continuously, with corresponding effects on entrance to higher education.

Vocational-technical secondary education includes a wide variety of options. Each of the courses leading to one of the 30 or so technical *baccalauréats* requires three years of study and prepares students for corresponding studies in higher education. Students may also choose to obtain, in descending order of qualification requirements and course demands, the technician diploma (*brevet de technicien*), the diploma of vocational studies (*brevet d'études professionelles*), or the certificate of vocational aptitude (*certificat d'aptitude professionelle*). A one-year course conferring no specialized qualification is also available. As an alternative, youths may opt for apprenticeship training in the workplace.

French university education

Higher education is offered in universities, in institutes attached to a university, and in the *grandes écoles*. Students attend for two to five years and sit either for a diploma or, in certain establishments, for university degrees or for a competitive examination such as the agrégation. Undergraduate courses last for three or four years, depending on the type of degree sought.

The universities went through a period of violent student dissatisfaction in the late 1960s. Reforms ensued encouraging decentralization, diversification of courses, and moderation of the importance of examinations. Nevertheless, the failure or dropout rate in the first two years is still high, and there are marked differences in status among institutions and faculties.

Teachers are graded according to the results of a competitive academic examination, and their training and qualifications vary by grade. The five grades range from the elementary teacher to the highly qualified graduate agrégé, who enjoys the lightest teaching load and the highest prestige and who teaches at the secondary level or higher. The differences have long been a matter of concern, as has the entrenchment of the higher levels of the teaching establishment. The system has resisted reforms calling for more uniformity in teacher status, changes in method and content orientation, teacher cooperation, interdisciplinarity, and technological familiarity. Reforms to extend the level of common education, to increase options at the upper secondary level, to strengthen the technological component, and to introduce steps to improve the link between school and work have nonetheless been achieved. Internal reform proposals include the more flexible organization of time and content and the addition of extracurricular activities appropriate to the real life of youth and society. Government forays into decentralization have promoted community links at the school level and school program initiatives. The outcomes will at best affect the system gradually, however.

Other European countries. Most eastern European education systems follow the old Soviet model (see below). In western Europe many countries have been influenced by the British, German, and French systems, but there are numerous variations, some of which are treated here.

Italy. Education in Italy up to 1923 was governed by the Casati Law, passed in 1859, when the country was being unified. The Casati Law organized the school system on the French plan of centralized control. In 1923 the entire national school system was reformed. The principle of state supremacy was reinforced by introducing at the end of each main course of studies a state examination to be taken by pupils from both public and private schools.

Eight years of schooling has been compulsory since 1948, although this plan was not realized until 1962. The five-year elementary school, for pupils aged six to 11, is followed by the undifferentiated middle or lower secondary school (*scuola media*) for pupils from 11 to 14. There continues to be a strong private (mainly Roman Catholic) interest in preschools and in teacher training for elementary and preschool levels.

Although reform proposals call for an extension of the unitary principle through the five-year upper secondary level, this level is highly diversified, with classical and scientific *licei* (schools) and a vast array of programs in vocational and industrial technical institutes. Shorter courses are given in institutes for elementary teachers and in art schools.

Italian university education

Entrance to Italian universities is gained by successful completion of any of the upper secondary alternatives. Universities are basically the only form of postsecondary education. They require the passing of a variable number of examinations, at the end of which the students sit for a degree (*laurea*), which gives them the title of *dottore*. To be able to exercise any profession, such as that of lawyer, doctor, or business consultant, the student must take a state examination. Students who do not complete their studies in the normal period of time, from four to six years, may remain at the university for several years as *fuori corso* ("out of sequence").

The unification of the lower levels and the expansion of academic and particularly vocational-technical alternatives at the upper level are notable advances, but the Italian education system still suffers from fragmentation and lack of articulation. Indications of low achievement and regional inequalities, in spite of relatively heavy public investment, suggest problems with system effectiveness. The force of conservative political, religious, and educational resistance to change is likely to maintain divisions of policy and outcome.

The Netherlands. The first modern school law in the Netherlands was passed in 1801, when the government laid down the principle that each parish had the right to open and maintain schools. A debate between the proponents of denominational and nondenominational schools went on during the 19th century. The controversy was closed by a law of 1920, which declared that denominational schools were fully equal with state schools, both types being eligible for public funds. The resultant decentralization is unique. Roughly two-thirds of the Dutch school-age children attend private schools. In return for public funds, the private school, which may be Protestant, Roman Catholic, or secular, must provide a curriculum equivalent to that offered by the public schools.

Religious-philosophical diversity is a characteristic feature of Dutch schools. Secondary education comprises four main types, which may be further differentiated: pre-university, general, vocational, and miscellaneous, which may be part-time. Selection decisions are strongly influenced by examinations. Preprimary and primary schools were recently combined into single eight-year schools for children aged four to 12. Other recent changes include the growth of vocational education at the postsecondary level and the increase in opportunity for females, as indicated by increasing enrollment at higher levels and by the estab-

lishment of special programs, such as that giving women whose schooling was interrupted the chance to return and finish their education.

Switzerland. The Swiss constitution of 1874 provided that each canton or half canton must organize and maintain free and compulsory elementary schools. The federal government exercises no educational function below the university level, except to help finance the municipal and cantonal schools. The Swiss school system thus consists of 26 cantonal systems, each having its own department of education, which sets up its own school regulations. The Swiss Conference of Cantonal Directors of Education has increased its efforts to achieve some educational unity, but great diversity remains.

In general, schooling is compulsory for eight or nine years, beginning at the age of six or seven. The elementary and lower secondary curriculum continues to stress mathematics and language. Cantonal differences in the training of elementary-school teachers remain a matter of concern, but provisions for additional training of in-service teachers are good. Each cantonal system begins to diversify at the lower secondary level and is even further differentiated at the post-compulsory upper secondary level. The pupil's future professional life is a decisive factor in the selection of post-compulsory schooling. Most pupils enter one of the many vocational courses, in which apprenticeship has long played a serious role. Among preuniversity schools, three types have been added to the two traditional ones emphasizing classical languages; the new schools stress mathematics and science (1925), modern languages (1972), and economics (1972). New proposals favour the consolidation of the preuniversity schools.

Swedish educational reforms

Sweden. After World War II the Swedish government began to extend and unify the school system, which had historically been the domain of the Lutheran church. In 1950 the National Board of Education introduced a nine-year compulsory comprehensive school, with differentiation of pupils postponed until late in the program. This *grundskola* replaced all other forms in the compulsory period by 1972–73. Following the unification of the elementary and lower secondary levels was the systematic integration of the upper secondary level, covering ages 16 to 19. This *gymnasieskola* uses organizational and extracurricular means of integration, but students are separated into 25 "lines," of which many are general-academic but most are vocational. Reforms have been implemented to make higher education available to more people, and adult education is encouraged.

The Swedish reform has attracted much attention in Europe for several reasons. It achieved the earliest unequivocal unification of the compulsory-school sector. While moving toward increased levels of integration in the system, the reciprocity of differentiation and integration was used as a principle of school development. As a result, the vocational sector was incorporated into the general upper secondary school. Theory and practice were recognized as components of all programs. The reform process, which specified a long period of experimentation and voluntary action (1950 to 1962) and a correspondingly long period of implementation (1962 to 1972), was singularly well conceived to build planning into participation and practice. The resultant organization is stable but open to change on the same principles. Thus, the new equality thrust goes beyond establishing equal opportunity to providing compensatory measures, even though they sometimes limit free choice, as, for example, in the use of sex quotas to bring women or men into occupations where they had been underrepresented.

Attention has also been focused on the Swedish approach to recurrent education, which introduces the idea of interchanging school and work as early as the secondary level. The coordination of school and work life, which is a worldwide goal, is not only built into institutional programs in Sweden but is also pursued there at a grass-roots level through local councils.

(J.A.L./R.L.Sw./R.F.L.)

The United States. As the United States entered the 20th century, the principles that underlie its present educational enterprise were already set. Educational sovereignty rested in the states. Education was free, compulsory, universal, and articulated from kindergarten to university, though the amount of free schooling varied from state to state, as did the age of required school attendance. Although a state could order parents to put their children to their books, it could not compel them to send them to a public school. Parents with sectarian persuasions could send their offspring to religious schools. In principle there was to be equal educational opportunity.

American principle of equal educational opportunity

Expansion of American education. Though such principles remained the basis of America's educational endeavour, that endeavour, like America, has undergone a vast evolution. The once-controversial parochial schools have not only continued to exist but have also increasingly drawn public financial support for programs or students. The currency of privatization, carrying the idea of free choice in a private-sector educational market, strengthens the bargaining position of religious as well as other private schools. The issue of equality has succeeded the issue of religion as the dominant topic of American educational debate. Conditions vary markedly among regions of the country. Definitions of equal opportunity have become more sophisticated, referring increasingly to wealth, region, physical disability, race, sex, or ethnic origin, rather than simply to access. Means for dealing with inequality have become more complex. Since the 1950s, measures to open schools, levels, and programs to minority students have changed from the passive "opportunity" conception to "affirmative action." Measured by high-school completion and college attendance figures, both generally high and continually rising in the United States, and by standardized assessment scores, gains for blacks and other minority students have been noteworthy from the 1970s. Although state departments of education use equalization formulas and interdistrict incentives to reach the poorest areas under their jurisdiction, conditions remain disadvantageous and difficult to address in some areas, particularly the inner cities, where students are mostly minorities. City schools often represent extremes in the array of problems facing youth generally: drug and alcohol abuse, crime, suicide, unwanted pregnancy, and illness; and the complex situation seems intractable. Meeting the needs of a racially and ethnically mixed population has, however, turned from the problem of the cities and from an assimilationist solution toward educational means of knowing and understanding the disadvantaged groups. States have mandated multicultural courses in schools and for teachers. Districts have introduced bilingual instruction and have provided instruction in English as a second language. Books have been revised to better represent the real variety in the population. The status of women has been given attention, particularly through women's studies, through improved access to higher education (women are now a majority of U.S. college students) and to fields previously exclusive to men, and through attempts to revise sexist language in books, instruction, and research.

Programs of special education

The idea persists that in the American democracy everyone, regardless of condition, is expected to have a fair chance. Such is the tenet that underlay the establishment of the free, tax-supported common school and high school. As science pointed the way, the effort to bridge the gulf between the haves and have-nots presently extended to those with physical and mental handicaps. Most states and many cities have long since undertaken programs to teach the handicapped, though financially the going has been difficult. In 1958 Congress appropriated $1 million to help prepare teachers of mentally retarded children. Thenceforward, federal aid for the handicapped steadily increased. With the Education for All Handicapped Children Act of 1975—and with corresponding legislation in states and communities—facilities, program development, teacher preparation, and employment training for the handicapped have advanced more rapidly and comprehensively than in any other period. Current reforms aim to place handicapped children in the least restrictive environment and, where possible, to "mainstream" them in regular schools and classes.

As the century began, American youths attended an eight-year elementary school, whereupon those who continued

went to a four-year high school. This "eight–four system" prevailed until about 1910, when the "six–three–three system" was introduced. Under the rearrangement, the pupil studied six years in the elementary and three in the junior and senior high schools, respectively. Both systems are in use, and there has been a change at the elementary–junior high connection to include a system in which children attend an elementary school for four or five years and then a middle school for three or four years. The rapid growth of preschool provisions has made available a wide, but mainly nonpublic, network of education for younger children.

In 1900 only a handful of lower-school students—some 500,000—advanced into high school. Of those who took their high-school diploma during this early period, some three out of every four entered college. The ratio reversed, as high-school enrollments swelled 10-fold in the first half of the 20th century, with only one of every four high-school graduates going on to higher learning.

By 1980, more than three-fourths of students completed high school, with about half of all high-school graduates entering college or post-secondary education. More recently, it is not the completion rate but the high-school-dropout rate that is measured. In the last two decades of the 20th century, the dropout rate stabilized at about 5 percent per year, with the greatest proportion occurring in low-income families.

From such experimental programs as the Dalton Plan, the Winnetka Plan, and the Gary Plan, and from the pioneering work of Francis W. Parker and notably John Dewey, which ushered in the "progressive education" of the 1920s and '30s, American schools, curricula, and teacher training have opened up in favour of flexible and cooperative methods pursued within a school seen as a learning community. The attempt to place the nature and experience of the child and the present life of the society at the centre of school activity was to last long after progressive education as a defined movement ended.

Some retrenchment occurred in the 1950s as a result of scientific challenges from the Soviet Union in a period of international political tension. Resulting criticisms of scientific education in the United States were, however, parried by educationists. America's secondary school attuned itself more and more to preparing the young for everyday living, accommodating the generality of young America with courses in automobile driving, cookery, carpentry, writing, and the like. In addition to changes in the form of earlier practical subjects, the curriculum has responded to social issues by including such subjects as consumer education (or other applications of the economics of a free-enterprise society), ethnic or multicultural education, environmental education, sex and family-life education, and substance-abuse education. Recent interest in vocational-technical education has been directed toward establishing specialized vocational schools, improving career information resources, integrating school and work experience, utilizing community resources, and meeting the needs of the labour market.

Expansion of American high-school curriculum

National prosperity and, even more, the cash value that a secondary diploma was supposed to bestow upon its owner enhanced the high school's growth. So did the fact that more and more states required their young to attend school until their 16th, and sometimes even their 17th, birthday. Recently, however, economic strains, the ineffectiveness of many schools, student violence, and troubled school situations in which the safety of children and teachers has been threatened have led to questions about compulsory attendance.

Criticisms have also been leveled at the effects on education of idealism in the 1960s. The resulting emphases on alternatives in lifestyle and on deinstitutionalization were, in their extreme form, destructive to public education. They were superseded by conservative attitudes favouring a return to the planning and management of a clearly defined curriculum.

Increasingly since the 1970s, many parents have chosen to educate their children at home. About one percent of the school-aged population was being educated in this way in the 1990s. The choice of homeschooling is controversial, and it is not always permanent; over the course of their children's education, parents might opt for a combination of homeschooling and private or public education.

The dramatic fall in scores on the Scholastic Aptitude Test (a standardized test taken by a large number of high-school graduates) between 1963 and 1982 occasioned a wave of public concern. A series of national, state, and private-agency reviews followed. The report of the National Commission on Excellence in Education, *A Nation at Risk* (1983), set the tone putting new emphasis on quality of school performance and the relation of schooling to career. The main topics of concern were the curriculum, standardization of achievement, credentialing, and teacher preparation and performance. Curriculum reforms have accentuated the academic basics, particularly mathematics, science, and language, as well as the "new basics," including computers. Computers have become increasingly important in education not only as a field of study but also as reference and teaching aids. Children are being taught to use computers at earlier ages; and more and more institutions are using computer-assisted instruction systems, which offer interactive instruction.

By the end of the 20th century, charter schools represented another strategy for improving public education by broadening parents' choices for their children and increasing accountability. These privately managed, publicly funded schools had been approved in a majority of states.

The reports on the state of education also expressed concern for gifted children, who have tended to be neglected in American education. Until psychologists and sociologists started to apply their science to the superior child, gifted children were not suspected of entertaining any particular problems, apart from occasionally being viewed as somewhat eccentric. Eventually, however, augmented with federal, state, and sometimes foundation money, one city after another embarked on educational programs for the gifted and talented child. From the 1970s, gifted children were directly recruited into special academic high schools and other local programs. American education is still aimed at broadening or raising the level of general provision, however. The concepts introduced by Howard Gardner, through books such as *Multiple Intelligences* (1993) and *Intelligence Reframed* (1999), did much to expand an understanding of learning to include such "intelligences" as the spatial, musical, linguistic, logical, kinesthetic, naturalist, and personal. Gardner's theory promoted teaching methods that aimed to cultivate a variety of skills and talents in children.

Federal involvement in local education

Although the U.S. Constitution has delegated educational authority to the states, which have in turn passed on the responsibility for the daily administration of schools to local districts, there has been no lack of federal counsel and assistance. Actually, national educational aid is older than the Constitution, having been initiated in 1787 in the form of land grants. Seventy-five years later the Morrill Act disbursed many thousands of acres to enable the states to promote a "liberal and practical education." In 1867 the government created the federal Department of Education under the Department of the Interior and, in 1953, established the Office of Education in the Department of Health, Education, and Welfare. As the independent Department of Education from 1980, this agency has taken a vigorous role in stating national positions and in researching questions of overall interest.

Financing of education is shared among local districts, states, and the federal government. Beginning with the Smith–Lever Act of 1914, Congress has legislated measure upon measure to develop vocational education in schools below the college plane. A new trail was opened in 1944, when the lawgivers financed the first "GI Bill of Rights" to enable veterans to continue their education in school or college.

During the 1960s, school difficulties experienced by children from disadvantaged families were traced to lack of opportunities for normal cognitive growth in the early years. The federal government attempted to correct the problem and by the mid-1960s was giving unprecedented funding to compensatory education programs for disadvantaged preschool children. Compensatory interven-

tion techniques include providing intensive instruction and attempting to restructure home and living conditions. The Economic Opportunity Act of 1964 provided for the establishment of the Head Start program, a total program that was designed to prepare the child for success in public schools and that includes medical, dental, social service, nutritional, and psychological care. Head Start has grown steadily since its inception and has spawned similar programs, including one based in the home and one for elementary-school-age children. In the 1970s child development centres began pilot programs for children aged four and younger. Other general trends of the late 1970s include: extending public schools downward to include kindergarten, nursery school, child development centres, and infant programs; organizing to accommodate culturally different or exceptional children; including educational purposes in day care; extending the hours and curriculum of kindergartens; emphasizing the early-childhood teacher's role in guiding child development; "mainstreaming" handicapped children; and giving parents a voice in policy decisions. Early-childhood philosophy has infiltrated the regular grades of the elementary school. Articulation or interface programs allow preschool children to work together with first graders, sharing instruction. Extended to higher grades, the early-childhood learning methods promote self-pacing, flexibility, and cooperation.

Changes in higher education. The pedagogical experimentalism that marked America's elementary learning during the century's first quarter was less robust in the high school and feebler still in the college. The first venture of any consequence into collegiate progressivism was undertaken in 1921 at Antioch College, in Ohio. Antioch required its students to divide their time between the study of the traditional subjects and the extramural world, for which, every five weeks or so, they forsook the classroom to work at a full-time job. In 1932 Bennington College for women, in Vermont, strode boldly toward progressive ends. Putting a high value on student freedom, self-expression, and creative work, it staffed its faculty largely with successful artists, writers, musicians, and other creative persons, rather than Ph.D.'s. It also granted students a large say in making the rules under which they lived.

Experiments at Antioch, Bennington, Chicago, and Harvard

Such developments in America's higher learning incited gusty blasts from Robert M. Hutchins, president and then chancellor of the University of Chicago from 1929 to 1951. He recommended a mandatory study of grammar, rhetoric, logic, mathematics, and Aristotelian metaphysics. One consummation of the Hutchins prescription is the study of some 100 "great books," wherein reside the unalterable first principles that Hutchins insisted are the same for all men always and everywhere.

The vocationalism that Hutchins deplored was taken to task by several others, but with quite different results—notably by Harvard in its report on *General Education in a Free Society* (1945). Declaring against the high school's heavy vocational leaning, it urged the adoption of a general curriculum in English, science, mathematics, and social science.

In the great expansion of higher education between about 1955 and 1975, when expansionist ideas about curriculum and governance prevailed, colleges became at times almost ungovernable. New colleges and new programs made the higher-education landscape so blurred that prospective students and admissions officers in other countries needed large, coded volumes to characterize individual institutions. The college curriculum, like that of the high school, was altered in response to vocal demands made by groups and had expanded in areas representing realities of contemporary social life. Internal reviews, undergraduate curriculum reforms, and the high standards set by some universities demonstrated to some observers that quality education was being maintained in the university. Other critics, however, felt that grade inflation, the multiplication of graduate programs, and increasing economic strains had led to a decline in quality. Financial problems and conservative reactions to the more extreme reforms led some universities to place a strong emphasis on management.

The junior college

Probably the most significant change in higher education has been the establishment and expansion of the junior college, which was conceived early in the century by William Rainey Harper, president of the University of Chicago. He proposed to separate the four-year college into an upper and a lower half, the one designated as the "university college" and the other as the "academic college." The junior college is sometimes private but commonly public. It began as a two-year school, offering early college work or extensions to secondary education. It has since expanded to include upper vocational schools (including a wide range of technical and clerical occupations), community colleges (offering vocational, school completion, and leisure or interest courses), and pre- or early-college institutions. Junior colleges recruit from a wide population range and tend to be vigorous innovators. Many maintain close relationships with their communities. Colleges limited to the undergraduate level, especially in articulated state systems, may not differ much from well-developed junior colleges.

Professional organizations. American educators began to organize as early as 1743, when the American Philosophical Society was founded, and they have been at it increasingly ever since. Not a few of their organizations, such as the American Historical Association, the Modern Language Association of America, and the American Home Economics Association, are for the advancement of some specialty. Others are more concerned with the interests of the general educational practitioner. Of these the National Education Association (NEA) is the oldest. Founded in 1857, it undertook "to elevate the character and advance the interest of the teaching profession." Despite its high mission, it threw off no sparks, and it was not until after 1870 that it began to grow and prosper. With headquarters in Washington, D.C., the NEA conducts its enormous enterprise through a brigade of commissions and councils. A youngster by comparison, the American Federation of Teachers, an affiliate of the AFL-CIO, was formed in 1916. Through collective bargaining and teachers' strikes, it has successfully obtained for teachers better wages, pensions, sick leaves, academic freedom, and other benefits. The distinction between a union and a professional organization is neither as clear nor as important an issue as it was in earlier days.

Such bodies as the American Association of Colleges for Teacher Education, the American Association of University Professors, the American Educational Research Association, the National Commission on Teacher Education and Professional Standards, and the National Council for Accreditation of Teacher Education have laboured industriously and even with a fair success to bring order and dignity to the teaching profession. Nevertheless, teaching has become an increasingly arduous profession in the United States. Even the security formerly assocated with the profession is in question as waves of teacher shortages and surpluses generate frantic responses by educational authorities. Recent educational reviews have addressed teaching inadequacies by encouraging prospective teachers to earn degrees in other subjects before beginning studies in the field of education. They have recommended establishing proficiency tests, regular staff-development activities, certification stages, and workable teacher-evaluation and dismissal procedures. They insist on the necessity for the reform and evaluation of training programs, and some have questioned the institutional context of teacher training.

(A.E.M./R.F.L.)

Elder members of the British Commonwealth. *Canada.* Although a Canadian nation had been formed by the end of the 19th century, separate political, economic, and geographic influences continued through the 20th century to restrain unified educational development. The historical principle of maintaining minority rights resulted in a truly pluralistic cultural concept, recognized to some extent in religious and linguistic concessions in schools. Each provincial system developed unilaterally, thus producing separately centralized educational units; and, even within a province, the evolving principle of local responsibility and the sparseness of settlement in many areas of Canada challenged the effectiveness of simple control principles. Different production emphases and differential advantages of territorial acquisition after confederation in 1867 cre-

ated basic inequalities among the provinces, with a corresponding effect on schools. Finally, European principles of education were slow to be reconciled with those evolving out of the North American environment. Canadian educational development has consequently been marked by eclectic, pragmatic actions rather than by philosophically or politically unified decisions.

It is nevertheless possible, because of a common national experience and because of the communication stimulated by national development, to describe education in national terms. Educational movements afoot in the early 20th century and associated with "progressive education" (such as child study, kindergarten development, and curriculum integration) had a relatively mild impact on traditional practices and forms. Instruction in the Canadian school remained essentially teacher-centred, with a strong emphasis on obedience and conformity.

Traditional versus progressive education

The major change in school structure occurred at the secondary level. The standard eight-year elementary program was first extended by continuation classes or schools alongside exclusive secondary schools, producing an uneven, overlapping postelementary structure. In the 1930s an expanded school population, reaching into the secondary grades, led to decisive action on compulsory attendance and to standardization of high-school provisions. Junior high schools were introduced in some provinces as a transitional level between elementary and secondary schooling, while some provinces simply developed junior and senior stages of a total secondary program. The two extremes in secondary development were probably represented by Québec and the west. In the French-speaking schools of Québec, the secondary system consisted of private classical colleges leading to a *baccalauréat* on the one side and terminal courses in special schools or institutes on the other. Only after 1956 were public high schools with a variety of courses established. The administration of the system was unified under a ministry of education in 1964, although with continuing provision for local school boards of a distinctly Roman Catholic or Protestant nature. In the western provinces, large regional schools and composite high schools were developed extensively, Alberta having proceeded apace in this direction. British Columbia, following the Chant Commission Report in 1960, reorganized its secondary program to include five core streams, only one of which was academic-technical.

Canadian educational reforms

In general, the secondary curriculum has been modified by expanding the catalog of optional subjects and by reorganizing to include new courses of study. Secondary schools in Canada are now mainly comprehensive and enroll about 85 percent of the age group. After extensive provincial reviews in the 1980s, emphasis has been returned to academic standards and newly placed on the relation of education to work, in response to the economic needs both of society and of the individual. This new emphasis may include teaching specific job skills and industrial information, coordinating vocational and academic studies in school programs, and cooperating with industry through work-study programs. Alternatives to the basic choice between university preparation and a general terminal course have appeared.

In response to the requirements of an expanded school population in the first half of the century and to the later demand for increased access, particularly for women, native Canadians, immigrants, and low-income groups, changes to structure, curriculum, and methods have occurred regularly since the 1960s. Many revisions originated with developments in the United States but took a particularly Canadian form. The first wave of reforms emphasized openness (open-area schools and classrooms, curriculum choice), comprehensiveness (composite high schools, consolidated rural schools, group work, and peer cooperation), and continuity up the school ladder (although with an abundance of alternatives). From the late 1970s, reforms shifted toward renewed emphasis on basic learning, selection of students, moral and social values, increased administrative control, and assessment procedures for school, system, and aggregate student performance.

The educational scene shows characteristics of both periods of reform. Some of the notable innovations include: the provision of preschool classes in most elementary schools or systems; the use in early elementary grades of new educational methods developed at the preschool level; a concentrated attempt to decrease newly discovered functional illiteracy at all levels, including the adult level; the rapid introduction of electronic learning programs and instructional assistance; and direct concern with values instruction, usually secular and oriented to both personal and social issues. Both the attempt to reconcile individual educational requirements with the demands of mass systems and the current emphasis on essential subject matter have led to a search for new techniques of selecting and transmitting knowledge in schools.

The most demanding issues of the second half of the century have reached beyond the traditional time and scope of public schooling: early-childhood education, adult education, private schooling, postsecondary education, and bilingual multicultural provisions. Whether as a reflection of concern over the direction of public schools, of an increasingly pluralistic society, or of affluence among parents, private-school attendance has risen steadily. It is still a small proportion of the school-age group in Canada (less than 5 percent), but the increase in interest as well as in attendance has put pressure on provincial governments for funding. Most provinces now offer limited grants to authorized private schools, though at a level far below public-school financing.

Consistent with Canada's claim to multicultural social development and bolstered by the Canadian Charter of Rights and Freedoms, multicultural and bilingual emphases have made perhaps the strongest single impact on schooling. French-language instruction, both as a mother tongue and as a second language, has expanded in traditionally English-speaking areas. Restrictions have been placed on English-language schooling in Québec as the French-language population struggles for cultural survival in North America. Court challenges against required Christian religious exercises and religious instruction in elementary schools have been successful. Demands have been made to give attention to other languages as languages of instruction and to revise the exclusively Western bias of curriculum content.

A new dimension in higher education was added with the establishment of provincial universities in the west (1901–08). This completed a set of regional patterns for university development that has continued to this day. Canadian universities have, within these patterns, drawn their criteria from French, British, or American models. From the 1950s, a boom in Canadian higher education has led to increasingly independent considerations on the role of universities in Canadian development. While the 1950s and '60s saw a great expansion of universities, the 1970s and '80s saw rapid growth in postsecondary, nonuniversity education in provincially funded colleges. These colleges all offer some range of vocational programs. Their relationships with universities vary: some offer university transfer programs (Alberta); some offer university prerequisites (Québec); some have no formal relationship (Ontario). With an increasing student population in a wider range of postsecondary alternatives, the rationalization, planning, and funding of this sector is a primary issue for provincial governments.

Regional patterns of Canadian universities

The administration of public education is the exclusive responsibility of the provinces, which have worked out schemes of local authority under provincial oversight. Although the specific structure of the departments of education varies among the provinces, they conform to a basic structure. Each is headed by a politically appointed minister of education, who may be advised by a council. The main functions of educational supervision are usually carried out through specific directorates for such areas as curriculum, examinations, vocational education, teacher training and certification, and adult education. Three developments, however, strengthened local autonomy in educational administration. Throughout the second quarter of the 20th century, consolidation of rural schools and administrative units took place in the west, thus resulting in stronger educational units more competent to act independently. Moves toward regional decentralization, especially

in Ontario, Québec, and New Brunswick, produced rather independent subprovincial units. Finally, urban development led to relatively autonomous city school operations. Provincial authority has been reemphasized, however, with the demands for better system articulation and for standardization of requirements, programs, and testing.

Federal influences in Canadian education

Canada's federal government has no constitutional authority in education and therefore maintains no general office dealing directly with educational matters. Federal activities in education are nevertheless carried out under other areas of responsibility, and certain functions of an office of education are subsumed under the secretary of state. The Council of Ministers of Education, Canada, brings together the chief educational officers of the provinces and ensures national communication at governmental level. Under its responsibility for native peoples and its jurisdiction over extra-provincial territories, the federal government, through the Department of Indian Affairs and Northern Development, finances and supervises the education of Indians and Eskimo. In the Yukon, schools are administered by the territorial government, though largely financed from Ottawa.

Through agricultural and technical assistance acts in 1913 and 1919, the federal government began to promote vocational education, and this principle was extended through emergency programs in the depression years of the 1930s and during World War II. More recently, vocational programs of wide scope have been introduced on a principle of federal support and provincial operation. The Technical and Vocational Assistance Act of 1960 was followed by a great surge in vocational education, including the construction of new schools and school additions, special institutes, and the preparation of vocational teachers. Program definitions in this area have become ever broader.

The federal government has maintained and supported the education of armed-forces personnel. Research and development in higher education are promoted directly through grants from national research councils for social sciences and humanities, for the natural sciences and engineering, for medicine, and for the arts. Statistics Canada disseminates organized statistical information on schools and on social factors affecting education. Perhaps less direct but of great importance are national agencies operating in the area of mass communications media, such as the National Film Board. Together, the activities of the federal government not only support but also strongly influence certain areas of education and complete a picture of local-provincial-federal involvement in Canadian education.

Australia The 20th-century development of Australian education continued to be influenced by British models and to be characterized by the exercise of strong central authority in the states. Yet, because Australian national development has taken place entirely in this century, increasing attention has been given to the role of education in nation building.

Educational systems were built through the establishment of primary schools by the end of the 19th century, the extension of these through continuation programs, and the development of state secondary schools in the early part of the 20th century. The independent secondary schools that offered the bulk of secondary education before 1900 continued to be influential, either as components of the separate Roman Catholic system or as "elite" private schools of denominational or nondenominational character, but the growth of state systems carried the state high schools into numerical prominence.

The early development of educational systems before and around the turn of the century was a crude beginning, the minimal provisions being accentuated by poor teacher preparation, administrative thrift schemes, and excess in the exercise of administrative authority. Improvement of these conditions and systematic positive development can be dated from the Fink Report of 1898 in Victoria and similar reform appeals in other states between 1902 and 1909. The steady pace of progress from that time was broken by a surge of growth and innovation in Australian institutions after World War II.

Education in small, isolated communities throughout the vast Australian area has required special attention. As a means of reaching isolated children and adults, correspondence education was begun in 1914 in Victoria, and other states followed after 1922. The procedures have been gradually refined and the levels extended. More formal early efforts included the introduction of provisional schools, itinerant teachers, and central schools in the outback. The small one-teacher bush schools became typical after federation in 1901. Much attention was given to methods of teaching in the one-room school, earning Australia international recognition for expertise in this area. Progress toward rural school consolidation began in Tasmania in 1936. The Tasmanian model combined special features of school independence, pupil freedom, involvement in agricultural projects, and parental cooperation with the "area school" movement. Recently, there has been a rapid decline in one-teacher all-age schools in Australia in favour of consolidated schools in central locations.

State and federal powers in Australia

Education is a state, rather than a federal, responsibility in Australia. Authority is concentrated in a state department of education. The political head is the minister of education, and the permanent official in charge is the director or director general of education. The main divisions of the department are those for primary, secondary, and technical education, each directed by a senior official; additional divisions, such as for special education or in-service training, are particular to the states. Department policy has been executed through a hierarchy of educational experts. Through the 1980s major changes in administrative organization took place in all state systems toward devolution of authority to local regions and schools. A corporate style of management has become current, using criteria of rationalization, effectiveness, and economic efficiency to guide organizational decisions. Although parties agree on many overall goals, disagreements among state authorities, powerful teachers' unions, and public groups promise the continuation of a politically volatile and changing administrative scene.

Since World War II, with the financial assets of exclusive income-taxing power, the commonwealth (federal) government has played an increasing role in educational development, particularly at the tertiary level. Through the States Grants Act in 1951, the Murray Report in 1957, the Martin Report in 1964, the Karmel Report in 1973, and a series of position papers leading to the 1988 Policy Statement on higher education, the federal government moved into the planning as well as the funding of post-secondary education concurrently with the states. After four decades of rapid expansion in higher education (from less than 50,000 students in 1948 to more than 400,000 in 1988), the government has set a course toward a unified national system at the tertiary level. The government has negotiated directly with higher education institutions, without the traditional buffer of consultative councils, and has moved directly to amalgamate institutions and otherwise to rationalize the system. The organizational rationale is based on the contribution of higher education to the national economic interest, and strategies link higher education to the training needs of the economy. System integrity, efficiency and output measures, and indications of privatization (a private university, tertiary fees, sale of educational services) characterize the political thrust. The Commonwealth Office of Education was established in 1945 to advise on financial assistance to the states and on educational matters generally, to act as a liaison agent among the states and between Australia and other countries, and to provide educational information and statistics. After several title changes, it became, in 1987, the Department of Employment, Education, and Training, bringing together education and training policy with employment strategy at the national level.

About three-quarters of Australian schools are public. The remainder are made up of Roman Catholic schools (which constitute about 80 percent of the nonpublic schools) and other private schools, many of which have considerable influence in the leadership of Australian society. The curriculum and syllabus for each program or course in the state schools is prescribed by the Department of Education, and nonpublic schools generally follow this standard. Since 1965 significant government funding has

been provided to private schools. There has been a resurgence of interest in and a consequent increase of influence from this sector again in recent years.

The Australian school structure

Primary schools are normally of six years' duration, to about age 12, though some schools retain the seventh year of the old pattern. Within primary schools, pupils are organized in grades and advance by annual promotion. Secondary education is offered for five or six years, generally in comprehensive schools. The minimum school-leaving age is 15 (16 in Tasmania). From the 1950s to the mid-1970s, rapid growth occurred throughout the systems, but especially at higher levels. The technical and further education (TAFE) sector has had a singular influence, operating at upper secondary and tertiary levels and providing widespread nonformal activities. TAFE colleges enroll about 700,000 students of school-leaving age annually and serve the great majority of Australian tertiary students. Recent moves have improved cross-crediting between TAFE and other tertiary institutions.

Since the 1970s, three educational goals have emerged: the first emphasizes equality, diversity, devolution, and participation; the second, national and social unity; the third, effective means of managing what had become, because of rapid growth, a huge and nearly ungovernable education sector. As a result, there have been internal reforms in teaching practice, curriculum, school organization, teacher education, and methods of assessment.

The attempts to increase the number of students continuing education and to improve or expand programs to serve the whole population have raised interest in system unification, including such issues as establishing common curricula and stronger Australian content, improving the transition from school to work, and providing equal opportunity for Aborigines, the disabled, and other groups designated as disadvantaged. The government has recently highlighted recognition of the contribution of Aboriginal cultures as well as of Australian studies.

The emphasis on management techniques may conflict with socially broader objectives. The enormous amount of debate current in Australian education has heightened national interest but has hardened ideological lines. The immediacy of political decisions for education and the momentum of present activity will continue to produce system change.

New Zealand. The religious and regional issues that have fettered educational development in other countries of the British Commonwealth were basically settled in New Zealand when the decisions were made in the last quarter of the 19th century to provide wholly secular primary schools and administrative centralization. The major issue in the 20th century has been the achievement of equal educational opportunity. Although New Zealand has accepted the responsibility to educate each child—without racial, social, or narrowly intellectual restriction—to the limits of the child's ability, the unification of the total system to this end has proved quite difficult.

New Zealand's goal of equal educational opportunity

The Education Act of 1914 consolidated the changes that had taken place since 1877. In subsequent reform periods during the '30s and after World War II, barriers to pupil progress through the system were removed or modified. In 1934 the school-leaving certificate examination was established on a broader basis than the university entrance examination, and, in 1936, the proficiency examination governing secondary entrance was abolished. In 1944–45 the school-leaving age was raised to 15; a common core of early secondary studies, including English, social studies, general science, mathematics, physical education, and a craft or fine-arts subject, was established; and universities agreed to accept accredited-school courses without further examination for university entrance. These actions illustrate a gradual but steady facilitation of access through an increasingly coordinated system. The recommendations of the Currie Commission (1962) and the provisions of the Education Act of 1964 continued this direction.

Since 1877 education has been supervised and funded by a central Department of Education, which is headed politically by a minister and permanently by a director general. Administrative duties are generally handled locally, however. Secondary schools are administered by their own boards of governors and primary schools by elected regional boards of education. Universities receive grants negotiated by the University Grants Committee, and grants for other tertiary institutions are administered by the Department of Education. Three regional offices and teams of primary and secondary inspectors link the central Department of Education and the network of local authorities. Education is free until the age of 19 for qualified pupils. University tuition is also paid for successful students.

New Zealand children generally start school at the age of five years and spend eight years in primary school. The secondary system developed through the growth of three separate kinds of school: (1) the district high school, which represented more or less a secondary "top" on a primary school, (2) the independent, academic, one-sex secondary school proper, and (3) the technical school, which took shape between 1900 and 1908. The isolated position of the fee-charging secondary schools of the 19th century was compromised by free-place legislation in 1903, and, by 1914, they were brought into the state system, though retaining a good deal of their independent status. The district high schools remained in the primary system, but their incorporation in the secondary inspection scheme and in secondary teacher classification placed them clearly within that sector of school operation. The technical high school evolved into a general high school with technical bias. Through common departmental inspection, curriculum, and examination standards, and through the effect of the movement for more general postprimary provisions after 1945, the secondary schools increasingly approximated a single pattern.

At the end of the 11th year of schooling, students take the School Certificate examination, a general test that partially determines admittance to the upper secondary level (12th and 13th years). About half the students leave school at this time. Youths qualifying for university entrance find that admission to professional schools is limited. Although the technical institutes and community colleges have been expanded since 1970, demand continues to increase for these programs. Enrollment in teachers' colleges has been limited due to a declining school population.

Private and rural schools

An extensive Roman Catholic private school system grew up after the secularization of state education. From 1970 these schools were subsidized, and after 1975 most became integrated into the state system and funded by the state.

Rural and native education have been given increasing attention in New Zealand. Consolidated schools, served by an extensive transportation system, have long been a feature of rural education. The expansion of community colleges and the establishment of rural education activity programs have extended regional opportunities. Children and adults in isolated districts are served by several correspondence schools. Maori education became a responsibility of the Department of Education in 1879. Since 1962 the government has attempted to balance the need for remediation of deficiencies in general schooling with Maori cultural rights. As in other countries, equity and the relationship between school and work are the two main issues facing the New Zealand school system. Together they represent growing social and economic demands which may not be compatible with the traditional order of schooling.

(R.F.L.)

REVOLUTIONARY PATTERNS OF EDUCATION

Russia: from tsarism to communism. *Before 1917.* At the turn of the 20th century the Russian Empire was in some respects educationally backward. According to the census of 1897, only 24 percent of the population above the age of nine were literate; by 1914 the rate had risen to roughly 40 percent. The large quota of illiteracy reflected the fact that, by this time, only about half the children between eight and 12 attended school. The elementary schools were maintained by the *zemstvo* (local government agencies), the Orthodox church, or the state, the secondary schools mainly by the Ministry of Education.

After the Revolution of 1905 the Duma (parliament) made considerable efforts to introduce compulsory elementary schooling. At the upper stages of the educational

system, progress was significant, too; nevertheless, the secondary schools (*gimnazii, realnyye uchilishcha*) were only to a small degree attended by students of the lower classes, and the higher institutions even less. Preschool education as well as adult education was left to the private initiative of the educationally minded intelligentsia, who were opposed to the authoritarian character of state education in the schools. In 1915–16 the minister of education, Count P.N. Ignatev, started serious reforms to modernize the secondary schools and to establish a system of vocational and technical education, which he regarded as most important for the industrialization of Russia. During the Provisional government (February to October 1917, old style), the universities were granted autonomy, and the non-Russian nationalities received the right of instruction in their native languages. The education system envisaged by the liberal-democratic and moderate Socialist parties was a state common school for all children based on local control and the direct participation of society.

1917–30. After the October Revolution of 1917, the Bolshevik Party proclaimed a radical transformation of education. Guided by the principles of Karl Marx and influenced by the contemporary movement of progressive education in the West as well as in Russia itself, the party and its educational leaders, Nadezhda K. Krupskaya and Anatoly V. Lunacharsky, tried to realize the following revolutionary measures as laid down in the party's program of 1919: (1) the introduction of free and compulsory general and polytechnical education up to the age of 17 within the Unified Labour School, (2) the establishment of a system of preschool education to assist in the emancipation of women, (3) the opening of the universities and other higher institutions to the working people, (4) the expansion of vocational training for persons from the age of 17, and (5) the creation of a system of mass adult education combined with the propaganda of communist ideas. In 1918 the Soviet government had ordered by decree the abolition of religious instruction in favour of atheistic indoctrination, the coeducation of both sexes in all schools, the self-government of students, the abolition of marks and examinations, and the introduction of productive labour. In 1919, special workers' faculties (rabfaks) were created at higher institutions and universities for the development of a new intelligentsia of proletarian descent.

Revolutionary experimentalism

During the period of the New Economic Policy (1921–27), when there was a partial return to capitalistic methods, the revolutionary spirit somewhat diminished, and the educational policy of party and state concentrated on the practical problems of elementary schooling, the struggle against juvenile delinquency, and the schooling of adult illiterates. When the policy of five-year plans began in 1928 under the slogan of "offensive on the cultural front" and with the help of the Komsomol (the communist youth league), the campaign against illiteracy and for compulsory elementary schooling reached its climax.

The Stalinist years, 1931–53. In connection with the policy of rapid industrialization and collectivization of farmers and with the concentration of political power in the hands of Joseph Stalin, the Soviet educational policy in the 1930s experienced remarkable changes. Starting with the decree of 1931, the structure and the contents of school education underwent the following process of "stabilization" in the next few years: (1) four years was laid down as the compulsory minimum of schooling for the rural districts, and seven years for the cities; (2) the new system of general education embraced the grades one to four (*nachalnaya shkola*), the grades five to seven, which continued the elementary stage on the lower secondary level (*nepolnaya srednyaya shkola*), and the grades eight to 10, which provided a full secondary education (*polnaya srednyaya shkola*); (3) the new curriculum was to provide the students with a firm knowledge of the basic academic subjects and was to be controlled by a system of marks and examinations; (4) the decisive role of the teacher within the educational process was reestablished, while the Pioneers and Komsomol organizations (for youth aged 10 to 15 years and 14 to 26 years, respectively) were above all to instill a sense of discipline and an eagerness for learning; (5) manual work disappeared from the school curriculum as well as from the teacher-training institutions. In addition, the ideas of progressive education were rejected, and older Russian traditions began to be cultivated. During World War II the idea of Soviet patriotism emerged fully, penetrating the theory and practice of education. The principles of the outstanding educator Anton S. Makarenko, with their emphasis on collectivism, gained ground upon the former influence of Western educational thought.

The institutions of higher learning were reshaped in the 1930s, too. The number of students in institutions providing secondary specialized education, usually called *tekhnikumy,* rapidly grew from one million in 1927–28 to 3.8 million in 1940–41. The number of students in institutions of higher education (*vyssheye uchebnoye zavedeniye*) grew from 168,554 to 811,700 in the same period. The main characteristics of higher education that developed in this period remained unchanged for the next decades: the paramount task of higher learning was to provide specialized vocational training within the framework of manpower policy and economic plans; strict control of the student's program was to be imposed by the central authorities; and the system of evening and correspondence instruction on the level of higher and secondary specialized education (*vechernyye i zaochnoye obrazovaniye*) was to parallel full-time studies.

During the 1940s, "labour reserve" trade schools and factory schools for skilled and semiskilled labour were filled by drafting youths between the ages of 14 and 17. In the period 1940 to 1958, an average of 570,000 persons were annually subjected to such recruitment. The draft first affected those students who were unsuccessful academically in regular secondary schools and could not achieve even the seventh grade. For youngsters of this kind and for people who could not continue general secondary education, schools for the working youth (*shkoly rabochey molodyozhi*) and schools for rural youth (*shkoly selskoy molodyozhi*) were established in 1943–44 as part-time institutions. The main features of education policy, developed in the late 1930s, remained in force after the war: the orientation of all kinds of schooling and training to the paramount necessities of the economic system; the inculcation of communist discipline and Soviet patriotic attitudes; and finally a rigid control of the whole educational system by party and state administration.

Labour training

The Khrushchev reforms. After the death of Stalin in 1953, changes in official policy affected both education and science. The 20th Party Congress in 1956 paved the way for a period of reforms inaugurated by Nikita S. Khrushchev. The central idea was formulated as "strengthening ties between school and life" at all levels of the educational system. The Soviet reform influenced to a high degree similar reforms in the eastern European countries.

The old idea of polytechnical education was revived, but mainly in the sense of preparing secondary-school students for specialized vocational work in industry or agriculture. Since the early 1950s there had been a growing imbalance between the output of secondary-school graduates desiring higher education and the economic demands of skilled manpower at different levels. The educational reforms of 1958 pursued the aim of combining general and polytechnical education with vocational training in a way that directed the bulk of young people after the age of 15 straight into "production."

The new structure of the school system after 1958 developed as follows: (1) the basic school with compulsory education became the eight-year general and polytechnical labour school, for ages seven to 15 (*vosmiletnyaya shkola*); and (2) secondary education, embracing grades nine to 11, was provided alternatively by secondary general and polytechnical labour schools with production training (*srednyaya obshcheobrazovatelnaya trudovaya politekhnicheskaya shkola s proizvodstvennym obucheniem*) or by evening or alternating-shift secondary general education schools (*vechernyaya smennaya srednyaya obshcheobrazovatelnaya shkola*).

The connection of study and productive work was to be continued during the course of higher education. Great emphasis was laid upon the further expansion of evening and correspondence education both at the level of sec-

ondary specialized education and at the level of the universities and other higher institutes. In the academic year 1967–68, 56.3 percent of all Soviet students in higher education (of the total number of 4,311,000) carried out their studies in this way.

The reform of 1958 also brought a transformation of the former labour-reserve schools into urban vocational-technical schools or rural schools of the same type (*gorodskiye i selskiye professionalno-tekhnicheskiye uchilishcha*). As a rule these schools required the completion of the eight-year school, but in fact there were many pupils with lower achievements; the length of training was from one to three years, depending upon the type of career.

Collective education

Besides introducing polytechnic education and productive labour, the Khrushchev reforms emphasized the idea of collective education from early childhood. Preschool education for the age group up to seven years was to be rapidly developed within the newly organized unified crèches and nursery schools (*yasli i detskiye sady*); and, as a new type of education, boarding schools (*shkoly-internaty*) that embraced grades one to eight or one to 11 had been created in 1956. Some party circles wanted this kind of boarding education for the majority of all young people, but development lagged behind planning, and the idea of full boarding education was later abandoned.

The polytechnization of the Soviet school system as it took shape during the Khrushchev period turned out, in the course of its realization, to be a failure. A revision of the school reform was carried out between August 1964 and November 1966 that brought about several important results: (1) the grade 11 of the secondary school (except for the evening school) was abolished; general education returned to the 10-year program; (2) vocational training in the upper grades was retained only in a small number of well-equipped secondary schools; and (3) a new curriculum and new syllabi for all subjects were elaborated. After 1958 hundreds of secondary schools for gifted pupils in mathematics, science, or foreign languages were developed, besides the well-known special schools for music, the arts, and sports. They recruited students mainly from the urban intelligentsia and were therefore sometimes criticized by adherents of egalitarian principles in education.

From Brezhnev to Gorbachev. Leonid I. Brezhnev assumed leadership after Khrushchev retired in 1964. On Nov. 10, 1966, a decree was issued outlining the new policy in the field of general secondary education. A union–republic Ministry of Public Education was established to augment the already existing central agencies for higher and secondary specialized education and for vocational-technical training. The main aim of educational policy in the 1970s was to achieve universal 10-year education. In 1977 it was claimed that about 97 percent of the pupils who graduated from the basic eight-year school continued their education at the secondary level. An important step toward the realization of universal secondary education was the creation of secondary vocational-technical schools (*srednye professionalno-tekhnicheskiye uchilishcha*) in 1969. These schools offered a full academic program as well as vocational training. Preschool education for children under seven years of age was extended: enrollments in nursery schools, kindergartens, and combined nursery–kindergarten facilities increased from 9.3 million in 1970 to 15.5 million in 1983. The number of institutions for higher education also grew steadily (from 805 in 1970 to 890 in 1983), meeting regional demands. Day, evening, and correspondence courses were provided.

The expansion of secondary education

The quantitative gains achieved during this period were not matched by corresponding improvements in the quality of education. Government authorities, as well as teachers and parents, expressed growing dissatisfaction with student achievement and with student attitude and behaviour. The youngsters themselves often felt alienated from the official value system in education. Furthermore, there was a growing imbalance between the careers preferred by general-school graduates and the national economic requirements for skilled manpower—an unforeseen result of the policy of universal secondary education. Therefore, in 1977 the scope of labour training in the upper grades of the general school was enhanced in order to provide youngsters with a basic practical training and to direct them into so-called mass occupations after leaving school.

In 1984, two years after Brezhnev's death, new reforms of general and vocational education were instituted. Teachers' salaries, which had been lower than other professional incomes, were raised. The age at which children entered primary school was lowered from seven to six years, thus extending the complete course of general-secondary schooling from 10 to 11 years. Vocational training in the upper grades of the general school was reinforced. To meet the requirements of computer literacy, appropriate courses were introduced into the curricula of the general school, even though most schools lacked sufficient equipment. The main emphasis, however, was placed on the development of a new integrated secondary vocational-technical school that would overcome the traditional barriers between general and vocational education.

Perestroika and education. The 1984 reform of Soviet education was surpassed by the course of economic and structural reforms (*perestroika*) instituted since 1986 under the leadership of Mikhail S. Gorbachev. In February 1988 some earlier reforms were revoked, including the compulsory vocational training in the general school and the plans to create the integrated secondary school. Universal youth education was limited to a nine-year program of "basic education," with subsequent secondary education divided into various academic and vocational tracks. The newly established State Committee of Public Education incorporated the three formerly independent administration systems for general schooling, vocational training, and higher education. Even more important was the rise of an educational reform movement led by educationists who favoured an "education of cooperation" (*pedagogika sotrudnichestva*) over the authoritarian and dogmatic principles of collective education that originated in the Stalin period. These theorists advocated individualizing the learning process, emphasizing creativity, making teaching programs and curricula more flexible, encouraging teacher and student participation, and introducing varying degrees of self-government in schools and universities as a part of the proclaimed "democratization" of Soviet society.

Education in the non-Russian republics

Post-Soviet education. The fall of the Soviet Union and the emergence of the Russian Federation in 1991 led to many changes in the education system. International exchanges among students, teachers, and researchers, especially at the upper levels, reflect the attempt to broaden the formerly isolated nature of education. The concept of choice has been introduced: for example, teachers now have some say in the textbooks they use, and parents or students have some choice in schools attended or curricula pursued.

Financing of education has been difficult, with decreasing funding available to support teacher salaries and new textbooks. Through such programs as the Education Innovation Project (to improve textbooks) and the Education Restructuring Support Project (to assist vocational education), the World Bank has become one of many global institutions supplementing the needs of Russia's schools and universities. (O.A./Ed.)

China: from Confucianism to communism. *The modernization movement.* The political and cultural decline of the Manchu dynasty was already evident before the 19th century, when mounting popular discontent crystallized into open revolts, the best known of which was the Taiping Rebellion (1850–64). The dynasty's weakness was further exposed by its inability to cope with the aggressive Western powers during the 19th century. After the military defeats administered by the Western powers, even Chinese leaders who were not in favour of overthrowing the Manchus became convinced that change and reform were necessary.

Most of the proposals for reform provided for changes in the educational system. New schools began to appear. Missionary schools led the way in the introduction of the "new learning," teaching foreign languages and knowledge about foreign countries. New schools established by the government fell under two categories: foreign-language schools to produce interpreters and translators and schools

for military defense. Notable among the latter were the Foochow Navy Yard School to teach shipbuilding and navigation and a number of academies to teach naval and military sciences and tactics.

China's defeat by Japan in 1894–95 gave impetus to the reform movement. A young progressive-minded emperor, Kuang-Hsü, who was accessible to liberal reformers, decided upon a fairly comprehensive program of reform, including reorganizing the army and navy, broadening the civil service examinations, establishing an Imperial University in the national capital and modern schools in the provinces, and so on. The imperial edicts in the summer of 1898 spelled out a program that has been called the Hundred Days of Reform. Unfortunately for China and for the Manchu dynasty, conservative opposition was supported by the empress dowager Tz'u-hsi, who took prompt and peremptory action to stop the reform movement. The edicts of the summer were reversed and the reforms nullified. Frustration and disappointment in the country led in 1900 to the emotional outburst of the Boxer Rebellion.

Hundred Days of Reform and the aftermath

After the Boxer settlement even the empress dowager had to accept the necessity of change. Belatedly, she now ordered that modern schools, teaching modern subjects such as Western history, politics, science, and technology, along with Chinese classics, be established on all levels. The civil service examinations were to be broadened to include Western subjects. A plan was ordered to send students abroad for study and recruit them for government service upon return from abroad. But these measures were not enough to meet the pressing demands now being presented with increasing forcefulness. Finally, an edict in 1905 abolished the examination system that had dominated Chinese education for centuries. The way was now cleared for the establishment of a modern school system.

The first modern school system was adopted in 1903. The system followed the pattern of the Japanese schools, which in turn had borrowed from Germany. Later, however, after establishment of the republic, Chinese leaders felt that the Prussian-style Japanese education could no longer satisfy the aspirations of the republican era, and they turned to American schools for a model. A new system adopted in 1911 was similar to what was then in vogue in the United States. It provided for an eight-year elementary school, a four-year secondary school, and a four-year college. Another revision was made in 1922, which again reflected American influence. Elementary education was reduced to six years, and secondary education was divided into two three-year levels.

Education in the republic. The first decade of the republic, up to the 1920s, was marked by high hopes and lofty aspirations that remained unfulfilled in the inclement climate of political weakness, uncertainty, and turmoil. The change from a monarchy to a republic was too radical and too sudden for a nation lacking any experience in political participation. The young republic was torn by political intrigue and by internecine warfare among warlords. There was no stable government.

A school system was in existence, but it received scant attention or support from those responsible for government. School buildings were in disrepair, libraries and laboratory equipment were neglected, and teachers' salaries were pitifully low and usually in arrears.

It was, nevertheless, a period of intellectual ferment. The intellectual energies were channeled into a few movements of great significance. The first was the New Culture Movement, or what some Western writers have called the Chinese Renaissance. It was at once a cordial reception to new ideas from abroad and a bold attempt to reappraise China's cultural heritage in the light of modern knowledge and scholarship. China's intellectuals opened their minds and hearts to ideas and systems of thought from all parts of the world. They eagerly read translated works of Western educators, philosophers, and literary writers. There was a mushroom growth of journals, school publications, literary magazines, and periodicals expounding new ideas. It was at this time that Marxism was introduced into China.

New intellectual movements during the republic

Another movement of great significance was the Literary Revolution. Its most important aspect was a rebellion against the classical style of writing and the advocacy of a vernacular written language. The classics, textbooks, and other respectable writings had been in the classical written language, which, though using the same written characters, was so different from the spoken language that a pupil could learn to read without understanding the meaning of the words. Now, progressive scholars rejected the heretofore respected classical writing and declared their determination to write as they spoke. The new vernacular writing, known as *pai-hua* ("plain speech"), won immediate popularity. Breaking away from the limitations of stilted language and belaboured forms, the *pai-hua* movement was a boon to the freedom and creativity released by the New Thought Movement and produced a new literature attuned to the realities of contemporary life.

A third movement growing out of the intellectual freedom of this period was the Chinese Student Movement, or what is known as the May Fourth Movement. The name of the movement rose from nationwide student demonstrations on May 4, 1919, in protest against the decision of the Paris Peace Conference to accede to the Japanese demand for territorial and economic advantages in China. So forceful were the student protests and such overwhelming support did they get from the public that the weak and inept government was emboldened to take a stand at the conference and refused to sign the Versailles Treaty. The students thus had a direct hand in changing the course of history at a crucial time, and from now on Chinese students constituted an active force on the political and social scene.

Education under the Nationalist government. Nationalist China rose in the mid-1920s amid a resurgence of nationalism and national consciousness stimulated by post-World War I developments. It was led by the Kuomintang, the political party organized by Sun Yat-sen, the founder of the republic. Cognizant of the popular appeal of nationalism, the Kuomintang set up a Nationalist government pledged to achieve national unity at home and national independence from foreign control as prerequisites to a program of modernization and national reconstruction. In education, it set out to systematize and stabilize a shaky and ill-supported school system and use it as a means of national regeneration. Schools were assured of financial support, however inadequate, and placed under strict supervision and firm control by public authorities.

State control and centralization of education

State control of education by means of centralized administration was instituted. Measures were adopted to correct the abuses and chaos that had resulted from the laissez-faire educational policy of the warlords. Decrees and regulations issued by the Nationalist Ministry of Education were strictly enforced, with the aid of a centrally administered system of inspection and accreditation. Detailed regulations covered the curricula of schools on all levels, minimum standards of achievement, teaching procedures, teachers' qualifications, and specifications for school buildings, libraries, laboratories, and the like. Private schools were permitted but were as subject to government control as public schools and were required to follow the same regulations with regard to curriculum and all other details.

A uniform system of schools was in effect throughout the country. Elementary education was provided in the four-year primary school, followed by the two-year higher elementary. In areas where there were not enough funds to support longer courses, there were abbreviated schools having only one or two grades. Theoretically, the government was committed to the goal of four-year compulsory education, but financial problems prevented an early realization of this goal. Adult education was given much attention in adult schools, in mass education projects, and in different forms of "social education." The latter term encompassed a variety of educational agencies outside the schools, such as libraries, museums, public reading rooms, recreational centres, music, sports, radio broadcasting, and films. Reduction of illiteracy was a major objective.

There were three parallel types of secondary education: the academic middle school, the normal school, and the vocational school. To counteract the traditional preference for the academic type of education, the government restricted the growth of the academic middle school. At the same time, vocational schools were encouraged.

Nationalist promotion of "practical studies"

A major objective of government policy was to promote "practical studies." In secondary education, "practical studies" meant the development of vocational and technical schools and more attention to science and laboratory experience in middle schools. In higher education, measures were taken to steer students away from liberal arts, law, education, and commerce to the "practical courses" of science, engineering, technology, agriculture, and medicine. Government grants for private as well as public colleges were usually designated for the science program. As a result of this policy, the years prior to World War II saw a steady increase of enrollment in the "practical courses" of study and a corresponding decline of enrollment in the arts–law–education–commerce courses. The increase of interest in science was also evident in the secondary schools.

It may be said that the thrust of educational policy in Nationalist China was to rectify the imbalance of the past, especially the nonvocational literary tradition of premodern days. In the attempt to counteract past tendencies, however, it was possible that the pendulum might swing to the other extreme. Some educators expressed the fear that the promotion of "practical studies" might lead to a narrow, utilitarian concept of education and a neglect of the humanities and social sciences. Others were uneasy over the danger of regimentation through centralized administration. Nevertheless, education under the Nationalist government did succeed in establishing an effective national system of education, promoting science and technical studies and correcting the abuses and irregularities of the earlier period. Thanks to dependable financial support, state schools and universities gained in prestige and academic performance until they were recognized as among the outstanding educational institutions of the country.

Other accomplishments of this period include the growth of postgraduate education and research, the general acceptance of coeducation in elementary and higher education, and the use of the Kuo yü (National Tongue) as an effective means of unifying the spoken language and thus overcoming the difficulties of local dialects.

Education under communism. The communist revolution aimed at being total revolution, demanding no less than the establishing of a new society radically different from what the orthodox communists called the feudal society of traditional China. This new society called for people with new loyalties, new motivations, and new concepts of individual and group life. Education was recognized as playing a strategic role in achieving this revolution and development. Specifically, education was called upon to produce, on the one hand, zealous revolutionaries ready to rebel against the old society and fight to establish a new order and, at the same time, to bring up a new generation of skilled workers and technical personnel to take up the multitudinous tasks of development and modernization.

The People's Republic of China generally makes no distinction between education and propaganda or indoctrination. All three share the common task of changing man. The agencies of education, indoctrination, and propaganda are legion—newspapers, posters, and propaganda leaflets, neighbourhood gatherings for the study of current events, as well as political rallies, parades, and many forms of "mass campaigns" under careful direction. It is evident that the schools constitute only a small part of the educational program.

When the Communists came to power in 1949, they took up three educational tasks of major importance: (1) teaching many illiterate people to read and write, (2) training the personnel needed to carry on the work of political organization, agricultural and industrial production, and economic reform, and (3) remolding the behaviour, emotions, attitudes, and outlook of the people. Millions of cadres were given intensive training to carry out specific programs; there were cadres for the enforcement of the agrarian law, the marriage law, the electoral law; some were trained for industry or agriculture, others for the schools, and so on. This method of short-term ad hoc training is characteristic of communist education in general.

Because the new Communist leaders had no experience in government administration, they turned to their ideological ally, the Soviet Union, for aid and guidance. Soviet advisers responded quickly, and Chinese education and culture, which had been Westernized under the Nationalists, became Sovietized. An extensive propaganda campaign flooded the country with hyperbolic eulogies of Soviet achievements in culture and education. The emphasis on Soviet cultural supremacy was accompanied by the repudiation of all Western influence.

Soviet influence on Chinese education

A major agency designed to popularize the Soviet model was the Sino-Soviet Friendship Association (SSFA), inaugurated in October 1949 immediately after the new regime was proclaimed. Headed by no less a personage than Liu Shaoqi, the second highest Chinese Communist leader, the association extended its activities to all parts of the country, with branch organizations in schools, factories, business enterprises, and government offices. In schools, students were urged to enlist as members of the association and to participate in its activities. In many schools more than 90 percent of the students became SSFA members. Throughout the nation, the SSFA sponsored exhibits, motion pictures, mass meetings, parades, and lectures to engender interest in the Soviet Union and in the study of Russian language, education, and culture.

Soviet advisers drew up a plan for the merging and geographic redistribution of colleges and universities and for the reorganization of collegiate departments and areas of specialization in line with Soviet concepts. Colleges and departments of long standing were eliminated without regard to established traditions or to the interests and scholarly contributions of their faculties. Russian replaced English as the most important foreign language.

From curriculum content to teaching methods, from the grading system to academic degrees, communist China followed the Soviet model under the tutelage of Soviet advisers, whose wisdom few dared question. Even the new youth organizations (which displaced the Boy Scouts and Girls Scouts) were comparable to the Pioneers and Komsomols of the U.S.S.R. According to one report, at the peak of the Sovietization frenzy, the first lesson in a Chinese-language textbook used in primary schools was a translation from a Russian textbook.

Never before in the history of education in China had such an extensive effort been made to imitate the education of a foreign country on such a large scale within such a short period of time. Nevertheless, there were many reasons why the campaign did not produce many lasting changes in Chinese education. Russian education and culture had not been well known in China, and the nation was not psychologically prepared for such a sudden and intensive dose of indoctrination to "learn from the Soviet Union." Students, teachers, and intellectuals in general, who would have reacted favourably to a reform to make education more Chinese, were skeptical of the wisdom of switching from Western influence to Soviet influence.

Ideology and education

Chinese leaders justified the indiscriminate imitation of the Soviet model on ideological grounds. The Soviet Union was the leader of the socialist countries; Lenin and Stalin were the shining lights that led the people of the world in their struggle for freedom and equality; the supremacy of the Soviet Union had proved the superiority of socialism over capitalism.

The paramount importance of ideology in education may also be seen in other ways. Ideological and political indoctrination was indispensable to all levels of schools and to adult education and all forms of "spare-time education." It consisted of learning basic tenets of Marxism–Leninism and studying documents describing the structure and objectives of the new government as well as major speeches and utterances of the party and government leaders. Its aim was to engender enthusiasm for the proletarian-socialist revolution and fervent support for the new regime. Class and class struggle were related concepts that occupied a central place in the ideology, and a specific aim of education was to develop class consciousness so that all citizens, young and old, would become valiant fighters in the class struggle. School regulations stipulated that 10 percent of the curriculum should be set aside for ideological and political study, but, in practice, ideology and politics were taught and studied in many other sub-

jects, such as language, arithmetic, and history. Ideology and politics permeated the entire curriculum and school life, completely dominating extracurricular activities.were completely dominated by politics and ideology.

Among the most important educational changes of this period was the establishment of "spare-time" schools and other special schools for peasants, workers, and their families. Adults attended the spare-time school after their day's work or during the lax agricultural season. Workers and peasants were admitted to these schools by virtue of their class origin. Political fervour and ideological orthodoxy replaced academic qualifications as prerequisites for further study. As a result of the Cultural Revolution of 1966–76, higher education was greatly curtailed and production and labour were emphasized. Mao Zedong, the Communist Party chairman, issued a directive sending millions of students and intellectuals into the rural areas for long-term settlement and "reeducation." He asserted that the intelligentsia could overcome the harmful effects of bourgeois-dominated education only by identifying with the labouring masses through engaging in agricultural and industrial production. Proletarian leadership was also emphasized, as "Mao Zedong thought propaganda teams," made up of workers, peasants, and soldiers who were well-versed in quotations from Chairman Mao but otherwise often barely literate, took over the management of almost all educational institutions.

Post-Mao and contemporary education. After Mao's death on Sept. 9, 1976, the new leaders lost no time in announcing a turnabout of ideological-political emphasis from revolution to development. They decreed that all effort should be directed toward "the four modernizations" (industry, agriculture, national defense, and science and technology). The primary task of education was to train the personnel needed to speed up the modernization program.

The post-Mao schools were very different from those of the revolutionary education. The conventional school system was reinstated. Full-time schools again became the mainstay of the educational system, with orderly advance from level to level regulated by examinations. School discipline was restored, and respect for teachers came to be expected of students. Serious study was not to be overshadowed by extracurricular activities, and clear distinctions were made between formal and informal education. When implementing the changes at that time, the communist leader Deng Xiaoping said that the main task of students was "to study, to learn book knowledge," and that the task of the school was to make "strict demands on students in their study . . . making such studies their main pursuit."

Acquisition of knowledge was revived as a legitimate aim of education. Academic learning and the development of the intellect returned after a decade of banishment. Academic standards were raised in the universities as well as in the lower schools. The "key schools," outstanding schools that elevate the standards of teaching and learning and serve as models for others, were reinstituted, complete with special libraries, laboratories, and highly qualified teaching staffs.

Key schools

Examinations were reintroduced. China's Law of Compulsory Education in 1986 instituted a minimum nine-year education; however, access to education in rural areas remains a challenge. Annual college entrance examinations are scheduled by the government. High-school graduates take the examination locally, indicating, in order of preference, the colleges they would like to attend if they pass.

Although in theory every college has a president, a vice president, deans, and the like, the real educational policymaker is the Communist Party organization in each school. School presidents or other administrators must often be party members, but even they cannot make decisions without the full cooperation of party representatives. Recently there have been demands for reforms giving more power to school administrators and faculty members.

Despite the renewed emphasis on academics, the national budget allotment for education is insufficient. Administrators and faculty members are underpaid. The government thus permits teachers to have secondary occupations.

The Communist Party and the intellectuals. Throughout China's long history, intellectuals considered themselves the preservers and transmitters of the precious culture of their country. Their road to success was not always smooth, but intellectuals were strengthened by the belief that once they won recognition as first-rank scholars they would be rewarded with position, honour, and lasting fame.

The attitude of the Chinese communists toward intellectuals has been influenced in large measure by their ideology. While workers and peasants were raised to the top position, intellectuals were downgraded because they were considered products of bourgeois and feudal education and perpetuators of bourgeois ideology. The communist policy was to "absorb and reform" intellectuals.

Intellectuals were made to undergo thorough thought remodeling to be "cleansed" of bourgeois ideas and attitudes. The remodeling began with relatively mild measures, such as "political study" and "reeducation." The policy became increasingly oppressive in the 1950s, when intellectuals were pressured to take part in the class struggle of the land reform and in orchestrated attacks on other intellectuals, such as university professors, writers, and artists. The intellectuals, especially those who had studied in Western schools or had been employed by Western firms, were forced to write autobiographies giving details of their reactionary family and educational background, pinpointing their ideological shortcomings, and confessing their failings.

Following Khrushchev's 1956 speech criticizing Stalin, violence broke out in Poland and Hungary. This worried Mao, who agreed to try Premier Zhou Enlai's proposal to relax the Communist Party's pressure on intellectuals. This resulted in the slogan "Let a hundred flowers bloom, a hundred schools of thought contend." Mao indicated that intellectuals would be allowed to speak freely.

The Hundred Flowers Campaign

The result, however, was unexpected and shocking. Once they began to speak freely, intellectuals unleashed a torrent of angry words, fierce criticisms, and open attacks upon the repressive measures under which they had suffered. Some recanted the confessions they had made under duress; others went so far as to denounce the Communist Party and its government. To avoid a more serious outburst of explosive ideas and emotions, the government decided to put a stop to the "blooming–contending." Outspoken critics were labeled rightists, and an anti-rightist campaign not only silenced intellectuals but also placed them under more restrictive controls than before. The "flowers" wilted and the "schools" were muffled.

During the Cultural Revolution, Mao's criticism of intellectuals instigated young radicals all over the country to join the struggle against intellectuals. Students were urged to slap and to spit at their teachers; insult, humiliation, and torture were common. Some teachers chose suicide. Others were sent to May 7th cadre schools or to the countryside to be reformed by labour.

After Mao's death and the repudiation of the radical extremists, intellectuals began to grow stronger. A movement called "Peking Spring" was launched in November 1978. Huge wall-posters condemning the communist regime appeared on Peking's so-called Democracy Wall. The movement's leaders expanded the modernization program by adding a fifth modernization which clearly emphasized democracy, freedom, and human rights. The "Peking Spring" movement was short-lived, but Chinese intellectuals in the United States and Hong Kong, as well as in China, continued to organize themselves and to advocate democracy and freedom. In China Fang Lizhi, an astrophysicist, toured university campuses speaking against the repression that he believed had killed the initiative and creativity of Chinese scholars. In the spring of 1989 a grand prodemocracy demonstration took place in T'ien-an Men Square. The university students took the lead, demanding a higher allotment of funds for education and protesting corruption, but people from all walks of life joined the demonstration. The movement drew attention and support both at home and abroad; but it was soon suppressed by the government, and the country, including educational affairs, continues to be controlled by the Communist Party. (T.H.C.)

PATTERNS OF EDUCATION IN NON-WESTERN OR DEVELOPING NATIONS

Effect of Japan's nationalism and economic growth

Japan. *Education at the beginning of the century.* Between 1894 and 1905 Japan experienced two conflicts, the Sino-Japanese and Russo-Japanese wars, which increased nationalistic feelings; it also experienced accelerated modernization and industrialization. In accord with the government's new nationalism and efforts to modernize the country, educational reform was sought. The Japanese education system took as its model the western European educational systems, especially that of Germany. But the basic ideology of education remained the traditional one outlined in 1890 in the Imperial Rescript on Education (Kyōiku Chokugo).

In 1900 the period of ordinary elementary schooling was set at four years, and schooling was made compulsory for all children. At the same time, the cost of compulsory education was subsidized from the national treasury. In 1907 the period of compulsory education was extended from four to six years. As the educational system gradually improved and as modernization progressed and the standard of living increased, school enrollments soared. The percentage of elementary-age children in school rose from 49 in 1890 to 98 in 1910.

In those days, boys and girls in primary school studied under the same roof, though in separate classrooms. In secondary education, however, there were entirely separate schools for boys and girls—the *chūgakkō*, or middle school, for boys and the *jogakkō*, or girls' high school, both aiming at providing a general education. Other than these, there was the *jitsugyōgakkō*, or vocational school, which was designed to afford vocational or industrial education for both boys and girls. All three secondary schools were for students who had completed the six- or four-year course of primary education.

As for the elementary and secondary curriculum, the Imperial Rescript on Education made it clear that traditional Confucian and Shintō values were to serve as the basis of moral education. This emphasis was implemented by courses on "national moral education" (*shūshin*), which served as the core of the curriculum. In 1903 a system of national textbooks was enacted, giving the Ministry of Education the authority to alter texts in accordance with political currents.

To meet the demand for an expansion of education, a new system for training primary-school teachers was established under the Normal School Order of 1886 and subsequently developed under the strong control of the government. All the normal schools were run by the prefectures, and none was private. At first only the graduates of the higher primary schools were qualified for the normal school, but in 1907 a new course was introduced for graduates of the middle schools and the girls' high schools. For training secondary-school teachers, there was after 1886 the *kōtō Shihangakkō*, or higher normal school for women. Additionally, temporary teachers' training institutes were established after 1902. These were all state-run. There were also state-run institutes for training vocational-school teachers.

Japan's imperial universities

For higher education, there were academies for the study of Confucianism, but a university of the European variety did not appear in Japan until 1877. In that year the University of Tokyo was founded, with four faculties—law, physical sciences, literature, and medicine. In the early years, research and education were dominated by foreigners: most programs were taught in the English language by English and American teachers or, in the medical faculty, in the German language by German instructors. In 1886 the University of Tokyo was renamed the Imperial University by imperial order and, as a state institution, was assigned to engage exclusively in research and instruction of such sciences and technology as were considered useful to the state. Modern Western sciences formed the core of this research and instruction, though some traditional Japanese learning was revived. Engineering and agricultural science were added to the four established faculties. Tokyo Imperial University borrowed much of the style and mode of the German universities and served as the model for the imperial universities established thereafter. Meanwhile, the higher middle schools established in 1886 were remodeled into the *kōtō-gakkō*, or higher schools, in 1894; and in the 20th century these higher schools developed as preparatory schools for the universities.

Higher education was advanced in another area by the College Order of 1903, which enabled certain upper-level private schools to be approved as *semmongakkō*, or colleges, and to receive the same treatment as state-run universities. Until then the private colleges had not been given a clear legal status and had been treated as rather inferior.

Education to 1940. The events of World War I and its aftermath tremendously influenced Japanese society. In the postwar days, Japan experienced the panic and social confusion that was sweeping many nations of the world. Moreover, the intensified leftist movement and the terrible Kantō earthquake of 1923 caused uncertainty and confusion among the Japanese. Nevertheless, the period was one that earned the name of the "Taishō democracy" era, which featured the dissemination of democratic and liberal ideas. It was also a period that marked Japan's real advancement on the world scene and the expansion of its capitalistic economy, all conducive to the flourishing of nationalism. It was quite natural that these social and economic changes should greatly influence education.

Efforts at reform

The Special Council for Education, established in 1917, was charged with making recommendations for school reforms that would adapt the nationalistic education system to the rapid economic growth. Their recommendations involved modifying the existing educational organizations rather than creating new ones. The reform emphasized higher education, though secondary education also grew remarkably. As for elementary education, the target of the reform was to improve the content and methods of education and to establish the financial foundation of compulsory education.

After World War I, the new educational movements generally called progressive in the West were introduced into Japan and came to thrive there. Many private schools advocating this "new education" were established, and the curricula of many state and public schools were also refashioned. The method of new education was gradually introduced into the state textbooks. Preschool education was also encouraged; a state-run kindergarten attached to Tokyo Girls' Normal School had been first established in 1876, and later many public and private kindergartens emerged, particularly after issuance of the Kindergarten Order in 1926.

Government aid for compulsory education was gradually put forward, and by 1940 this developed into a system whereby the government financed half the teachers' salaries and the prefectural governments the other half. Elementary education thus further expanded. Between 1910 and 1940 the number of elementary teachers and pupils almost doubled. In the latter year there were 287,000 teachers and 12,335,000 pupils.

Secondary education continued to be provided by the middle schools for boys, the girls' high schools, and the vocational schools. These schools increased remarkably both in numbers of institutions and in enrollments after World War I, reflecting the social demand. As a result, the secondary schools assumed more of a popular and less of an elitist character than they had evidenced in the Meiji era. In 1931 two courses were provided for the middle-school system; one was for those who advanced on to higher schools, and the other course was for those who went directly on to a vocation. Enrollments of all kinds leaped: whereas in 1910 the enrollments in middle schools, girls' high schools, and vocational schools had been 122,000 pupils, 56,200 pupils, and 64,700 pupils, respectively, the respective figures in 1940 were 432,000 pupils, 555,000 pupils, and 625,000 pupils.

Increases in enrollments, 1910–40

A drastic reform of higher education was instituted in 1918, when the University Order and the Higher School Order were issued on the recommendation of the Special Council for Education. Before that, there had been only the imperial universities, which were state-run. The order approved the founding of private universities and colleges. As a consequence, the old influential private col-

leges, or *senmongakkō,* rich in tradition, were approved as formal universities or colleges, resulting eventually in such famous universities as Keiō and Waseda. National colleges of commerce, manufacturing, medicine, and so on were also opened. In general, universities and colleges multiplied, numbering in 1930 as many as 46 (17 state, five public, and 24 private). College-preparatory education concurrently enlarged through the establishment of public and private higher schools under the Higher School Order. The higher schools were remodeled after the German *Gymnasium* and the French lycée and offered a seven-year course.

The schools could not keep pace with the mounting demand for education. The ratio of applicants to the total number of seats being offered at higher schools, for example, rose from 4.3 in 1910 to 6.9 in 1920 and 10.5 in 1926. Because pupils could not proceed from elementary to secondary schools, and from there to colleges or universities, unless they passed a competitive entrance examination at each stage, the importance and severity of the examinations grew with the number of applicants. Despite efforts by the Ministry of Education to revise and deemphasize the examination system, which was established in the Meiji era, its importance continues to the present day.

After World War I, social education, or education offered outside the formal school system, gained greater recognition in Japan. During the Meiji era, social education, then called "popular education," had been promoted by the Ministry of Education to encourage school enrollment, but by 1890 it had taken the form of adult education, attempting to enlighten middle- and working-class adults with public lectures and library resources. By 1929 social education had again become important as a result of the Ministry of Education's emphasis on youth organizations, supplementary vocational education, youth training, and adult education. The *jitsugyō hoshūgakkō,* or supplementary vocational schools, which had been built after 1893 as part-time educational institutions for working students, reached enrollments exceeding 1,277,000 by 1930. In 1935 *seinengakkō,* or youth schools, were newly established, uniting these supplementary vocational schools with the *seinen kunrenjo,* or youth-training centres, that had earlier been set up to provide military training for youth.

Education changes during World War II. The Manchurian Incident in 1931 escalated into the Sino-Japanese War of 1937, and national life became more and more militaristic. Education acquired an intensely nationalistic character. With the outbreak of war in the Pacific in 1941, the education system underwent emergency "reforms." Elementary schools were renamed *kokumingakkō,* or national schools, under the National School Order issued in 1941. The order proclaimed the idea of a national polity or spirit peculiar to Japan; the content and the methods of education were revised to reflect this nationalism. Moreover, the period of compulsory education was officially extended to eight years, though it actually remained six years because of the worsening war situation.

Militarism and nationalism

Secondary education was similarly made "national." In 1943 the Secondary School Order was issued in an attempt to unify all the secondary schools, but it also, because of the war, shortened secondary education to four years. In the same year the normal school was upgraded to the level of the professional schools. As the war worsened, students above the secondary schools were mobilized as temporary workers in military industries and agricultural communities in order to increase production, and a great number of students were sent to the battlefields. As a result, classes were virtually closed at schools higher than secondary toward the end of World War II.

Education after World War II. On Aug. 14, 1945, Japan accepted the Potsdam Declaration and surrendered unconditionally to the Allied powers. The overriding concern at the general headquarters (GHQ) of the Allied powers was the immediate abolition of militaristic education and ultranationalistic ideology. This was the theme of a directive issued by GHQ to the Japanese government in October 1945. In early 1946 GHQ invited the United States Education Mission to Japan, and it played a decisive role in creating a new educational system. The mission's report recommended thorough and drastic reforms of education in Japan. The report was subsequently adopted in its entirety as the basic framework for a new democratic educational system. The Education Reform Committee, which was directly responsible to the prime minister, was established to make recommendations for the implementation of the new education. Based on these recommendations the Japanese Diet passed a series of legislative acts that forged the foundation of postwar education.

The Fundamental Law of Education and the School Education Law, both enacted in 1947, and the Boards of Education Law of 1948 set the outlines of the new education. The prewar system was replaced by a democratic single-track system, in which school programs were integrated and simplified and the period of attendance was settled in six, three, three, and four years, respectively, for *shōgakkō,* or elementary schools, *chūgakkō,* or lower secondary schools, *kōtōgakkō,* or upper secondary schools, and *daigaku,* or universities. The period of compulsory attendance was extended to nine years; coeducation was introduced; and provisions were made for education for the physically handicapped and other special education.

The new Japanese school system

The reform of the content of education proceeded to reduce the strong state control of former days and to encourage teachers' initiative. State textbooks were abolished in favour of commercial ones, and schools were controlled locally by elective boards of education. *Shūshin* disappeared from the curricula and was replaced by new subjects, such as *shakaika,* or social studies, designed to prepare children for life in a democratic society. The educational reform also altered the character of the universities, which offered access to all citizens. The former institutions—universities, colleges, and normal schools—were reorganized into four-year universities and colleges. Teacher education was placed within the university system, and anyone who completed professional training was eligible for teacher certification. This reorganization had an immense impact upon the development of higher education.

Changes after the end of Allied occupation

The peace treaty of 1952 not only liberated Japan from the restraints of occupation but also allowed education there to be adjusted to intrinsic cultural and political orientations. Centralization of control increased with respect to administration, curriculum, textbooks, and teacher performance through a series of legislative and administrative measures in the 1950s. In addition, the political indoctrination of the leftist Japan Teachers' Union was hindered, and moral education was reintroduced as a requirement at the elementary and lower secondary levels. On the whole, however, the postwar educational reforms were retained and advanced, and their subsequent elaboration helped match Japan's rapid economic growth.

The postwar educational administration was organized into a three-tiered structure, with national, prefectural, and municipal components—all under the general supervision of the Ministry of Education, which also wields a considerable measure of authority over curricular standards, textbooks, and school finance, among other functions. Through its central, advisory role, the Ministry of Education has guided the development of egalitarian and efficient schooling in the postwar era.

The progressive curriculum, which emphasized child interest and was introduced from the United States immediately after the war, produced deteriorating student performance. Thus, during 1961–63 the Ministry of Education replaced that curriculum with a discipline-centred curriculum at the elementary and lower secondary levels in order to improve academic achievement, moral education, science and technical education, and vocational education. This curricular revision set the tone for later changes in the national curriculum. Each major curricular revision represented an educational response to a variety of social needs, above all economic.

The 1960s was a period of high growth for both the economy and education. The unprecedented economic growth was stimulated by an ambitious national plan to boost individual income, industry, and trade. Responding to the changing economic and industrial environment, enrollments in high schools and in colleges or universities increased, respectively, from 57.7 and 10.3 percent of

the eligible students in 1960 to 91.9 and 37.8 percent in 1975. Ninety percent of this increase in university and college enrollments was absorbed into poorly financed private institutions, which contributed to the deterioration of higher education. Problems also arose at the upper secondary level, where education remained rigidly uniform, even though students were increasingly diverse in ability, aptitudes, and interests. The inability of the postwar educational system to meet either student requirements or the insatiable demands for secondary and postsecondary education became of critical concern, and in 1971 the Central Council for Education recommended reforming Japan's education to eradicate these problems.

The Central Council initiated a sustained school reform debate that set the stage for the establishment, in 1984, of an advisory council on educational reform, which is directly responsible to the prime minister. The advisory council called for elimination of the uniformity and rigidity of education at all levels and for the enhancement of "individuality" through education. Its recommendations in 1987 included diversifying upper secondary education, improving moral education, encouraging greater local freedom and responsibility in developing curriculum, improving teacher training, and fostering diversity in higher education. Thus, Japan's educational policy is being directed toward meeting the diversified needs of the future. (A.Na./N.S.)

South Asia. *Preindependence period.* Amid the rising nationalism of the latter part of the 19th century, Indians became more and more critical of the domination of Western learning as imposed by the British rulers and demanded instead more attention to Indian languages and culture. The Indian National Congress, several Muslim associations, and other groups raised their voices against the British system of education. Nor were British authorities altogether blind to the needs of the country. When Baron Curzon of Kedleston arrived as viceroy in 1898, his determination to improve education was immediately translated into an order for a close survey of the entire field of education. It revealed: "Four out of five villages are without a school. Three boys out of four grow up without any education and only one girl out of forty attends any kind of school." Education had advanced, but it had not penetrated the country as the British had earlier expected.

Political conflicts involved in education in India

Curzon applied himself to the task of putting matters in order. He disapproved of the doctrine of state withdrawal and instead considered it necessary for the government to maintain a few institutions of every type as models for private enterprise to imitate. He also abandoned the existing policy of educational laissez-faire and introduced a stricter control over private schools through a vigilant policy of inspection and control. Such a policy aroused bitter feelings among some educated Indians, since it was believed that Curzon was bent on bringing the entire system of education under government control.

The main battle, however, was fought over the universities. With Eton and Balliol in mind, Baron Curzon set up the Indian Universities Commission of 1902 to bring about a better order in higher education. The commission made a number of important recommendations—namely, to limit the size of the university senates; to entrust teaching in addition to examining powers to universities; to insist on a high educational standard from affiliated colleges; to grant additional state aids to universities; to improve courses of studies; to abolish second-grade colleges; and to fix a minimum rate of fees in the affiliated colleges. The report was severely criticized, and the last two recommendations had to be dropped. Legislation in regard to the other proposals was passed despite bitter opposition in the legislature and the press.

The conflict resulted less from educational differences than from political opinions on centralization. In one part of the country, violent agitation had already started on the question of the partition of Bengal. In another, the patriot Bal Gangadhar Tilak declared: "Swaraj [self-rule] is our birthright." Thus, Baron Curzon's educational reforms were considered sinister in their intentions, and his alleged bureaucratic attitude was resented.

The administrative policy of Baron Curzon also gave rise to the first organized movement for national education. This effort was part of the swadeshi movement, which called for national independence and the boycotting of foreign goods. A body known as the National Council of Education, in Calcutta, established a national college and a technical institution (the present Jadavpur University) in Calcutta and 51 national schools in Bengal. These schools sought to teach a trade in addition to ordinary subjects of the matriculation syllabus. The movement received a great impetus, because the Calcutta Congress (1906) resolved that the time had arrived for organizing a national system of education. With the slackening of the swadeshi movement, however, most of the national schools were eventually closed. The effect of the movement was nevertheless noticeable elsewhere: Rabindranath Tagore started his famous school in West Bengal near Bolpur in 1901; the Arya Pratinidhi Sabha established *gurukulas* at Vrindāban and Hardwār; the Indian National Congress and the All-India Muslim League at their sessions in Allahābād and Nāgpur, respectively, passed resolutions in favour of free and compulsory primary education.

Swadeshi movement

In 1905 Baron Curzon left India. In order to pacify the general public, his successors modified his policy to some extent, but the main program was resolutely enforced. Although Indian public opinion continued its opposition, the reforms of Baron Curzon brought order into education. Universities were reconstituted and organized, and they undertook teaching instead of merely conducting examinations for degrees. Colleges were no longer left to their own devices but were regularly visited by inspectors appointed by the universities. The government also became vigilant and introduced a better system for inspecting and granting recognition to private schools; the slipshod system of elementary education was also improved. The number of colleges and secondary schools continued to increase as the demand for higher education developed.

In 1917 the government appointed the Sadler Commission to inquire into the "conditions and prospects of the University of Calcutta," an inquiry that was in reality nationwide in scope. Covering a wide field, the commission recommended the formation of a board with full powers to control secondary and intermediate education, the institution of intermediate colleges with two-year courses, the provision of a three-year degree course after the intermediate stage, the institution of teaching and unitary universities, the organization of postgraduate studies and honours courses, and a greater emphasis on the study of sciences, on tutorial systems, and on research work. The government of India issued a resolution in January 1920, summarizing the report of the commission. Since then, all legislation of any importance on higher education in any part of India has embodied some of the recommendations of the commission.

Meanwhile, World War I had ended, and the new Indian constitution in 1921 made education a "transferred" subject (that is, transferred from British to Indian control), entrusting it almost entirely to the care of the provinces. In each province, educational policy and administration passed into the hands of a minister of education, responsible to the provincial legislature and ultimately to the people. Although European-style education was still maintained as a "reserved" subject and was not placed under the control of the Indian minister of education, this anomaly was corrected by the Government of India Act of 1935, which removed the distinction between transferred and reserved subjects and introduced a complete provincial autonomy over education.

Generally, the new constitution of 1921 was considered inadequate by the Indian National Congress. In protest, Mahatma Gandhi launched the Non-cooperation Movement, the campaign to boycott English institutions and products. National schools were established throughout the country, and *vidyapeeths* ("national universities") were set up at selected centres. The courses of study in these institutions did not differ much from those in recognized schools, but Hindi was studied as an all-India language in place of English, and the mother tongue was used as the medium of instruction. These institutions functioned for a short time only and disappeared with the suppression of

Non-cooperation Movement

the Non-cooperation Movement. The Congress' struggle for self-rule, however, became more vigorous, and with it spread the national movement toward education to suit national needs. The Government of India Act of 1935 further strengthened the position of the provincial ministers of education, since the Congress was in power in major provinces. The developmental program of provincial governments included the spread of primary education, the introduction of adult education, a stress on vocational education, and an emphasis on the education of girls and underprivileged people. The importance of English was reduced, and Indian languages, both as subjects of study and as media of instruction, began to receive greater attention.

General educational trends, 1921–47

On this general background, educational developments from the inauguration of reforms in 1921 until independence in 1947 can be viewed. In the field of elementary education, the most important event was the passing of compulsory-education acts by provincial governments—acts empowering local authorities to make primary education free and compulsory in the areas under their jurisdiction. Another noteworthy feature was the introduction of Gandhi's "basic education," which was designed to rescue education from its bookish and almost purely verbal content by emphasizing the teaching of all school subjects in correlation with some manual productive craft. A general demand for secondary education developed with the political awakening among the masses. Schools in rural, semi-urban, and less advanced communities were established, as well as schools for girls. Some provision was made for alternative or vocational courses when the provincial governments started technical, commercial, and agricultural high schools and gave larger grants to private schools providing nonliterary courses. But the expected results were not achieved because of a lack of funds and of trained teachers. Secondary schools still concentrated on preparing students for admission to colleges of arts and sciences.

The period is also marked by a diminishing of the prejudices against the education of girls. The impetus came from the national movement launched by Gandhi, which led thousands of women to come out of the purdah for the cause of national emancipation. It was also realized that the education of the girl was the education of the mother and through her of her children. Between 1921–22 and 1946–47, the number of educational institutions for girls was nearly doubled.

In the field of university education, outstanding developments included (1) the establishment of 14 new universities, unitary as well as affiliating, (2) the democratization of the administrative bodies of older universities by a substantial increase in the number of elected members, (3) the expansion of academic activities through the opening of several new faculties, courses of studies, and research, (4) a substantial increase in the number of colleges and student enrollments, (5) the provision of military training and greater attention to physical education and recreational activities of students, and (6) the constitution of the Inter-University Board and the development of intercollegiate and interuniversity activities. With these improvements, however, the educational system of the country had become top-heavy.

The postindependence period in India. India and Pakistan were partitioned and given independence in 1947. Since then, there has been remarkable improvement in scientific and technological education and research, but illiteracy remains high (less than 40 percent of Indians aged four and older are literate). The new constitution adopted by India did not change the overall administrative policy of the country. Education continues to be the prime responsibility of the state governments, and the union (central) government continues to assume responsibility for the coordination of educational facilities and the maintenance of appropriate standards in higher education and research and in scientific and technical education.

In 1950 the government of India appointed the Planning Commission to prepare a blueprint for the development of different aspects of life, education being one of them. Since then, successive plans (usually on a five-year basis) have been drawn and implemented. The main goals of these plans have been to achieve universal elementary education; to eradicate illiteracy; to establish vocational and skill training programs; to upgrade standards and modernize all stages of education, with special emphasis on technical education, science, and environmental education, on morality, and on the relationship between school and work; and to provide facilities for high-quality education in every district of the country.

The education commissions and their recommendations

Since 1947 the government of India has also appointed three important commissions for suggesting educational reforms. The University Education Commission of 1949 made valuable recommendations regarding the reorganization of courses, techniques of evaluation, media of instruction, student services, and the recruitment of teachers. The Secondary Education Commission of 1952–53 focused mainly on secondary and teacher education. The Education Commission of 1964–66 made a comprehensive review of the entire field of education. It developed a national pattern for all stages of education. The commission's report led to a resolution on a national policy for education, formally issued by the government of India in July 1968. This policy was revised in 1986. The new policy emphasizes educational technology, ethics, and national integration. A core curriculum was introduced to provide a common scheme of studies throughout the country.

The national department of education is a part of the Ministry of Human Resource Development, headed by a cabinet minister. A Central Advisory Board of Education counsels the national and state governments. There are several autonomous organizations attached to the Department of Education. The most important bodies are the All-India Council of Technical Education (1945), the University Grants Commission (1953), and the National Council of Educational Research and Training (1961). The first body advises the government on technical education and maintains standards for the development of technical education. The second body promotes and coordinates university education and determines and maintains standards of teaching, examination, and research in the universities. It has the authority to enquire into the financial methods of the universities and to allocate grants. The third body works to upgrade the quality of school education and assists and advises the Ministry of Human Resource Development in the implementation of its policies and major programs in the field of education.

The central government runs and maintains about 1,000 central schools for children of central government employees. It has also developed schools offering quality education to qualified high achievers, irrespective of ability to pay or socioeconomic background. The seventh five-year plan (1985–90) specified that one such *vidyalaya* would be set up in each district. The state governments are responsible for all other elementary and secondary education. Conditions, in general, are not satisfactory, although they vary from state to state. Higher education is provided in universities and colleges.

From the 1950s to the '80s the number of educational institutions in India tripled. The primary schools, especially, experienced rapid growth because the states have given highest priority to the universalization of elementary education in order to fulfill the constitutional directive of providing universal, free, and compulsory education for all children up to the age of 14. Most but not all children have a primary school within one kilometre of their homes. A large percentage of these schools, however, are understaffed and do not have adequate facilities. The government, when it revised the national policy for education in 1986, resolved that all children who attained the age of 19 years by 1990 would have five years of formal schooling or its equivalent. Plans have also been made to improve or expand adult and nonformal systems of education. Dissension among political parties, industrialists, businessmen, teacher politicians, student politicians, and other groups and the consequent politicization of education have hampered progress at every stage, however.

The postindependence period in Pakistan. On Aug. 14, 1947, Pakistan emerged as a national sovereign state. For the new state the initial years proved to be a period essentially of consolidation and exploration. The constitution adopted in 1956 recognized the obligation of the state to

provide education as one of the basic necessities of life. The new constitution implemented by the National Assembly in 1973 made practically no changes to the original educational policy. The federal Ministry of Education, headed by the federal education secretary, oversees education in the federal capital territory and in national institutions and determines policies and standards. Provincial governments handle all other administrative duties.

Aims of Pakistani educational policy

Beginning in 1955, Pakistan adopted a series of five-year plans to improve economic and educational development. Among the objectives were: (1) to strengthen training programs for all categories of manpower, (2) to establish technical trade schools and vocational institutes, (3) to provide adequate machinery, materials, and books for workshops, laboratories, and other facilities, and (4) to strengthen and develop centres for advanced engineering studies. The National Education Policy of 1979 emphasized the need for improving vocational and technical education and for disseminating a common culture based on Islāmic ideology. Although it also announced plans for gradually replacing the four-tier school structure (primary, secondary, college, and university) with a three-tier structure consisting of primary (grades one through eight), secondary (grades nine through twelve), and higher education, the four-tier system remained in place at the turn of the 21st century. Literacy rates are a continuing concern (by the late 1990s only about two-fifths of the adult population was able to read and write).

The Pakistani government has accepted responsibility for providing free primary education for a length of time fixed provisionally at five years. At the end of the 20th century, about three-fourths of primary-age children were enrolled in schools; however, attendance was concentrated in urban areas and considerably higher among boys than girls. Religious classes providing Islāmic moral and sociocultural education have been taught in the schools since about 1980.

The postindependence period in Bangladesh. Comprising what was formerly the eastern wing of Pakistan, Bangladesh emerged as an independent sovereign state in December 1971. Thus, it shares its educational history with India until 1947 and with Pakistan from 1947 to 1971. After independence Bangladesh continued to follow the compulsory primary education scheme originally established by Pakistan. One of the country's most valued educational assets is its rich national language, Bengali.

Article 17 of the constitution of the People's Republic of Bangladesh declares that it is the duty of the state to provide education to all its children to such stage as may be determined by law. In 1973 and 1974 the government nationalized most of the primary schools, but it was found that about 33 percent of primary-school-age children in Bangladesh never went to school and that about 70 percent of those who did left school before attaining the minimum educational standard. By the mid-1990s, school attendance had increased to include roughly half of the school-age population (attendance rates are higher in urban areas). The literacy rate also grew, especially in cities, where more than half of the population was literate. In rural areas, however, more than half of the children enter adulthood illiterate. It has now been recognized that universalization of primary education for an overpopulated developing country like Bangladesh is a difficult task. Major reforms are under way to orient the educational system to a new social order inspired by the ideals of "nationalism, democracy, socialism, and secularism" on which the nation is founded.

The postindependence period in Sri Lanka. Sri Lanka gained independence in 1947. Successive governments have since continued the policy of democratizing education that began under British rule. The political and social changes ushered in during the pre-independence period paved the way for a gradual process of constitutional reforms. Schools and schooling are seen as great instruments of socioeconomic development.

Education is free from the kindergarten to the university level in all state and state-aided institutions. Although there are a few fee-levying private institutions, management of education is primarily a state responsibility. General education within the formal system is divisible into primary, junior secondary, and senior secondary education. There are few dropouts or grade repeaters at the primary level. Thus, the percentage of literacy rose from 57.8 (70.1 for males and 43.8 for females) in 1948 to 90.2 (93.4 males, 87.2 females) in 1995. At the junior secondary stage, instruction is provided according to a common curriculum that consists of religion and other subjects. Students at the senior secondary stage are streamed into science, commerce, or liberal arts courses.

The University Act of 1978 established the University Grants Commission and the University Services Appeals Board to provide for the establishment, maintenance, and administration of universities and other higher educational institutions together with their campuses and faculties. The National Institute of Education was established in 1987 to coordinate curriculum development, textbook development, teacher education, and eventually certification and entrance examinations. At the beginning of the 21st century, funding from such sources as the Asian Development Bank was being used to modernize school facilities and educational programs. (S.N.M./Ed.)

Traditional African education

Africa. Before the arrival of the European colonial powers, education in Africa was designed to prepare children for responsibility in the home, the village, and the tribe. It provided religious and vocational education as well as full initiation into the society. In sub-Saharan Africa it varied from the simple instruction given by fathers to children among the San of the Kalahari to the complex educational system of the sophisticated and highly organized Poro society of western Africa (extending over Liberia, Sierra Leone, and Guinea). The majority of ethnic groups in Africa fell somewhere between the San and the Poro with respect to the educational arrangements they provided for their youth.

Most societies offered rituals and rites of passage to mark the end of puberty and relied heavily upon custom and example as the principal educational agents. An exception to this pattern could be found in those areas where Islām had spread. Islām reached eastern Africa in the 9th and 10th centuries and western Africa in the 11th. It introduced the Arabic script, and, because knowledge of the Qur'ān became an important religious requirement, Qur'ānic schools developed. These schools concentrated on the teaching and memorization of the Qur'ān; some were little more than gathering places beneath a tree where teachers held classes. Qur'ānic schools placed young Africans in contact with Arab civilizations, and boys selected as potential leaders could attend higher educational institutions in the Arab world. Nevertheless, Islām touched but a small fraction of the total African population of sub-Saharan Africa.

Western-style schooling was introduced in most of Africa after the establishment of the European colonial powers. As African nations gained independence in the late 20th century, they abolished the racial segregation that had existed and instituted other sweeping reforms but, in general, they maintained the structure of the existing school systems, at least initially. Thus, in many cases, contemporary education can be understood in the context of former colonial status.

Access to education has been difficult in many parts of Africa, but the Internet has created new pathways for learning. The African Virtual University (AVU) allows students to earn credit for courses in a variety of subjects or vocational training programs. As a nonprofit organization based in Nairobi, Kenya, AVU has sponsored classes in more than a dozen African countries. Degree specializations have included computer science, electrical engineering, and computer engineering.

Ethiopia. Christianity was recognized in Ethiopia in the 4th century. For nearly 1,500 years all education was church-related and hence church-controlled, except in the eastern part of the country where the Islāmic population maintained Qur'ānic schools. In 1908 Emperor Menilek II created the embryonic government school system, modeling it on European systems. The real development of education, however, came after World War II under the direction of Emperor Haile Selassie. Despite his efforts, by 1969 less than 10 percent of the children between the

ages of seven and 12 were in school. Education at the secondary level benefited from the infusion of more than 400 Peace Corps teachers in the 1960s and early 1970s. The first Ethiopian colleges were founded in the 1950s. By 1970, 2,800 Ethiopian students were enrolled in higher education either in their own country or overseas.

In 1974 a military revolution overthrew the emperor. Ethiopia declared itself a socialist state and proclaimed that socialism would permeate all aspects of the society. The government's stated aims of education were (1) education for production, (2) education for scientific consciousness, and (3) education for social consciousness. Political alliance with the Soviet Union influenced educational reform. Polytechnical education, which emphasizes familiarizing children with the important branches of production and acquainting them with first-hand practical experience, was widely introduced by Soviet educational advisers. A number of Ethiopian students were sent to the Soviet Union or Eastern-bloc countries for higher education or to Cuba for schooling at the secondary level.

Socialist education

The structure of the Ethiopian school system remained unchanged from that established in the late 1950s. Children begin the 12-year program at age seven. Grades one through six make up the primary cycle, seven through eight the junior secondary cycle, and nine through 12 the senior secondary cycle. Students who pass the Ethiopian School Leaving Certificate Examination at the end of grade 12 are eligible for higher education, but space in the country's colleges and universities is limited.

Liberia. Education in Liberia, the oldest republic in Africa (1847), is distinctly different from that in any other African country. Liberia was founded by freed slaves from the United States, and its educational system was modeled on the American system. Public primary and secondary schools were established in the 19th century for the children of the settlers, but there was little money to extend schooling into the interior of the country for the indigenous people. Church schools were also established. The Western-style schools trained Liberians in the new settlements for work in offices. A few students were prepared for the legal or theological profession.

In 1912 a centralized educational system was established under a cabinet-level official, but, except for the establishment of a few secondary schools and colleges, nothing of importance happened until the end of World War II. In the prewar period three-fourths of the schools were either private or mission-run. Economic growth and the interest of President William V.S. Tubman in the 1950s resulted in a greater extension of education for indigenous Liberians. The educational system was organized to provide preprimary education for children aged four and five years, six years of elementary education for children aged six to 12, and three years each of junior and senior high school. Postsecondary education can be pursued at three leading institutions: the University of Liberia, sponsored by the government; Cuttington University College, administered and financially supported by the Episcopal church with some financial aid from the government; and the William V.S. Tubman College of Technology. The educational expansion started by President Tubman in the 1950s has, however, reached only a small fraction of the people. (Da.G.S.)

South Africa. From the time of the first white settlements in South Africa, the Protestant emphasis on home Bible reading ensured that basic literacy would be achieved in the family. Throughout the development from itinerant teachers to schools and school systems, the family foundation of Christian education remained, though it was gradually extended to embrace an ethnic-linguistic "family."

Early efforts to establish education in South Africa

Despite some major 19th-century legislation on the administration of education (1874 in the Transvaal and the Orange Free State, 1865 in Cape of Good Hope, 1873–77 in Natal) and some early efforts to establish free schools, political and linguistic problems impeded the development of public education before 1900. Natal had gone furthest in affirming government responsibility for education and setting up the necessary administrative machinery, but, by and large, provision for schooling remained voluntary and piecemeal until the beginning of the 20th century.

The South African, or Boer, War (1899–1902) suspended educational development entirely and confirmed the resolve of each white South African group to protect its own cultural prerogatives. When the Union of South Africa was created in 1910, it was a bilingual state, and, in education, English-speaking and Afrikaans-speaking schools were established for white Europeans. Furthermore, a political tightness and separateness increased among the Afrikaners after the war and strengthened their tendency to exclude nonwhites from the cultural and political life of the dominant society. The trend toward separate schools for linguistic and racial groups became a rigid practice in most of South Africa after union.

Church mission schools attempted to replace the preliterate tribal education of native Africans in the South African colonies. Established from 1789, they were dedicated to converting the natives to Christianity and generally inculcating an attitude of service and subservience to whites. These schools spread from 1823 to 1842, and colonial governments made occasional grants to them from 1854. Some mission schools included a mixture of races, but, by and large, segregation was established by custom. Although some exemplary schools followed rather liberal social and curricular policies, most schools held to narrowly religious content in their curricula. The mission schools were virtually brought into the state system through government subsidies and through provincial supervision, inspection, and control of teaching, curriculum, and examination standards.

The union and school systems

By the time the union was formed, the new provinces had each established school systems, structured mainly for European children but including provisions for other groups. Specific arrangements varied, but basically the systems were headed by a department of education under a director and controlled through an inspectorate. Three of the provinces had school boards that localized the department administration. Compulsory-attendance regulations were being effected for European children, while separate school developments were under way for other groups. The language of instruction had been established provincially, with both Afrikaans and English in use.

The South Africa Act of 1909 left the control of primary and secondary education with the provinces, while reserving higher education to the union government. The Union Department of Education, Arts, and Science became the central educational authority and expanded its responsibilities by accepting control of special sectors such as vocational, technical, and artistic education.

In 1922, when the Phelps-Stokes Commission on education in Africa offered its report, South Africa's example in the development of liberal and adaptable educational provisions for Africans, particularly in Natal and Cape Province, was held up for emulation. The passing of the tribal system was noted and efforts toward interracial cooperation complimented. It was obvious, however, that little of value to Africans was being done in the European-model schools and that noteworthy educational efforts were associated with special institutions, such as Lovedale School and University College of Fort Hare in the Cape.

Education under apartheid

Concern over African education in the 1940s led to the creation of the Eiselen Commission, whose report in 1951 accorded with the separatist racial views of the government that came to power in 1948 and laid the groundwork for subsequent apartheid ("apartness") legislation in education. That legislation included the Bantu Education Act of 1953. The National Education Policy Act of 1967 and a subsequent Amendment Act in 1982, along with the Constitution Act of 1983, also reflected apartheid policy. The provinces incorporated national policy into their own legislation and administration.

Fundamentally, the system of apartheid rested on three assumptions: that each cultural group should be encouraged to retain its identity and develop according to its "unique" characteristics; that, with a population of diverse racial-social groups, the way to ensure peaceful coexistence and general progress was through legal and institutional separation; and that the only agency capable of exercising overall responsibility for this development was the central government. Implementation of apartheid policy led to

a near-total separation of educational facilities for white, black, Coloured (mixed-race), and Indian (Asian) populations, with resulting divergence of opportunity between the extremes of black and white education.

Administration of education was divided between national departments and provincial authorities. Because education was differentiated by race, four separate systems were established. Education for whites was controlled by the Minister of National Education, and provincial–federal coordination was accomplished through a National Education Council and a Committee of Heads of Education. Education for Coloured and Indian population groups was administered through the legislative bodies representing these groups, the House of Representatives and the House of Delegates, respectively. Education for blacks was largely the responsibility of the black "homeland" governments. All four systems were supposed to follow the same basic organizational and curricular patterns. For blacks outside the homelands, the Department of Education and Training administered education.

Formal characteristics distinguishing the system of education for blacks included a slightly different school organization, designation of state-aided community schools with school committees, provision for limited African-language instruction, and separate administration. More important, however, were the effects of inequality on the system's operation. Although the government introduced a limited experiment in compulsory education, the dropout rate among blacks was high. Many pupils were educated in factory, mine, or farm schools that were less adequate than general schools. Teacher qualifications were lower for blacks than for the other groups. Illiteracy was high. Rural schools were crowded and short of materials. Few black pupils attended secondary schools.

There were some attempts to close the gap between black and white education at both lower and higher levels. The government proclaimed the principle of equal educational opportunity and from the 1970s sharply increased budget allotments for black education. Private and community efforts augmented schooling and introduced experimental integrated schools, and some private schools and white universities were opened to black students. Black schools remained severely inadequate, however, and the government's position that the immensity of the problem defied immediate solution conflicted with the demands of black activist student organizations, which multiplied after 1976 (partly through division) and intensified their resistance through strikes and boycotts. Violence and fear intruded on township schools and on black universities during the apartheid period.

By the Extension of University Education Act in 1959, nonwhites were barred from entrance to white universities, and separate university colleges were set up on an ethnic-linguistic basis. This well-organized system of differentiating groups began to break down, however, as first English and then Afrikaans universities stated their policies of admission by merit, as university decisions and legislation opened nonwhite universities to other groups, and as protests against government quotas on university admissions became increasingly effective. The universities became centres of agitation against apartheid.

A major government commission, conducted through the Human Sciences Research Council, in 1981 recommended that a single system of education under a single ministry be established. Although principles of the report were accepted, the government held to the cultural policy from which institutional separation was derived. The change from an ideological basis to a pragmatic basis for this separation, combined with the elimination of formal barriers to racial crossovers and black mobility in education, produced a policy that competed with revolutionary strategies for social change.

Post-apartheid reforms

Before the apartheid era came to an end during the early 1990s, South Africa began to address the crisis in African education. An Education Renewal Strategy was released in 1993. Discussions involving government officials, educators, parents, and students were initiated in the mid-1980s and were formalized in the 1990s. A single Ministry of Education was established in 1993.

Educational reform faced severe challenges, however. The primary obstacle was the limited amount of resources available for expenditure on education. School facilities in predominantly white schools were far superior to schools in black areas; many African schools—especially in rural areas—lacked primary necessities such as heat, plumbing, and electricity as well as advanced facilities such as science laboratories. Shortages of basic classroom supplies were common.

Teachers were often poorly trained, particularly in the rural schools. Many teachers in suburban school systems, who generally were the best qualified, were reluctant to move to rural schools. Efforts were accelerated to improve the teacher-training system: the previously discriminatory qualifications required for primary and secondary teachers as well as for teachers from the different racial groups were standardized. All teachers must complete a full secondary course plus a three-year training course.

Thus, in the early postapartheid period, class differences and geographic considerations began to become more characteristic of social division than race in South African schools. Improvement in the system depended largely on increased availability of resources for education, which in turn depended on a strong South African economy.

A shift to a more Afrocentric curriculum was an important element of South African educational reform during the 1990s. The government and private publishers created new curricula in which racial stereotypes were eliminated and the African perspective of South African history was emphasized. New approaches, including the use of oral histories, were introduced during the 1990s.

Some of the basic features of South African education continued into the postapartheid period. The system is organized into four three-year cycles: junior primary, senior primary, junior secondary, and senior secondary. Because the first year of the junior secondary cycle is taken in the primary school, the primary and secondary units are seven and five years, respectively (replacing an earlier eight-four organization). Schooling is compulsory for students of all races from age seven to 16.

The general high schools are predominantly academic but offer a range of streams. Specialized high schools, at the senior secondary level, offer technical, agricultural, commercial, art, and domestic science courses. Apprenticeship may be begun after the first year of the senior secondary phase (grade 10). Attempts are now being made to form regional comprehensive schools.

Private schools are found mainly in the northeast and in the Cape region. More than nine-tenths of South African white children and virtually all black children are in state schools.

South African university education

The tertiary sector of South African education includes universities, technikons (successors to the colleges of advanced technical education, offering programs of one to six years in engineering and other technologies, management, and art), technical colleges and institutes, and colleges of education. Technical centres, industrial training centres, and adult education centres extend training to early school-leavers. During the 1990s many black university students demanded reduced admission standards and increases in scholarships and faculty appointments for blacks.

Language is intimately related to politics and to African aspirations. It was the imposition of Afrikaans as the compulsory language of instruction that triggered the Soweto riots in 1976 and the subsequent wave of unrest. Black parents and students demanded recognition of their own language and culture (Africanization) as well as the access to the metropolitan culture of their own and other countries that English could provide. During the early postapartheid period, Afrikaans was dropped as a language of instruction for black students in favour of English and African languages. (R.F.I.)

General influences and policies of the colonial powers. During the colonial period, the first direct "educational" influences from outside came from religious missionaries, first Portuguese (from the 15th century) and then French, Dutch, English, and German (from the 15th to the 19th century). Starting from coastal bases, they undertook to penetrate into the interior and begin campaigns to convert

the black populations. The missions were the first to open schools and to develop the disciplined study of African languages, in order to translate sacred texts or to conduct religious instruction in the native tongues.

The partition of Africa by the colonial powers in the 19th and early 20th centuries led first to the establishment of mission schools and then to the establishment of "lay" or "public" or "official" schools. The importance of either the lay or the religious system depended on the political doctrines of the mother country, its institutions (a firmly secular state or one with a state religion), and the status of the colony and its history. But, whatever the system, the fundamental purpose of colonial instruction was the training of indigenous subaltern cadres—clerks, interpreters, teachers, nurses, medical assistants, workers, and so forth—all indispensable to colonial administration, businesses, and other undertakings. Though inspired by the system in the mother country, no colonial system was equivalent to its prototype. The intention was not to "educate" the subject peoples but to extend the language and policies of the colonizer.

Such a generalization, though, is subject to a slight qualification with reference to the religious missions. Both the missions and the political administrations wished to model the African man in accordance with their own needs and objectives. The religious missions, however, became involved in the cultures of the Africans through continual contact with them in the daily ministrations; they used African languages in instruction wherever the colonial administration permitted it. Moreover, for a long while, religious establishments were alone in offering vocational education, some secondary education, and even some higher education to Africans—frequently in the face of the fears or opposition of the colonial authorities.

Education in Portuguese colonies and former colonies. Angola and Mozambique shared a common historical legacy of hundreds of years of Portuguese colonization, and the general overall educational philosophy for both countries was the same until independence. For Portugal, education was an important part of its civilizing mission. In 1921, Decree 77 forbade the use of African languages in the schools. The government believed that since the purpose of education was integration of Africans into Portuguese culture the use of African languages was unnecessary. In 1940 the Missionary Accord signed with the Vatican made Roman Catholic missions the official representatives of the state in educating Africans. By the 1960s an educational pattern similar to that in Portugal had emerged. It began with a preprimary year in which the Portuguese language was stressed, followed by four years of primary school. Secondary education consisted of a two-year cycle followed by a three-year cycle. After 1963 two universities were opened, one in Angola and the other in Mozambique. In addition, postprimary education was offered in agricultural schools, in nursing schools, and in technical service courses provided by government agencies. Despite remarkable progress in the 1960s, primary education was available to few Africans outside urban areas, and even there, the proportion of African children in secondary schools was low.

Educational reforms after independence

Marxist governments triumphed in both Angola and Mozambique when independence came in 1975. Dissident groups, however, have maintained bloody civil wars in both countries that have had disastrous effects on the educational systems. The Popular Liberation Movement of Angola (Movimento Popular de Libertação de Angola; MPLA), which gained control of Angola when Portugal withdrew, had educational reform as one of its main objectives even during the fight for independence. A report of the first congress of the MPLA published in 1977 provided a blueprint that has been followed with few deviations. Marxism-Leninism is stressed as the base for the educational system. The training of all people to contribute to economic development is a major objective. Eight years of primary education is to be universal. Secondary education, offered on a limited basis, includes vocational as well as college preparatory courses. At the University of Angola special emphasis has been placed on scientific and engineering courses.

The governing Mozambique Liberation Front (Frente de Libertação de Moçambique; Frelimo) introduced its educational system in the areas it controlled even before independence. After independence, at the Third Congress of Frelimo in February 1977, policies for the transition to socialism were formalized. While Marxism would provide a foundation, the particular needs of Mozambique would be addressed. All schools were nationalized, but because most of the teachers, who were Portuguese, had left the country, the government was faced with a tremendous teacher shortage. Crash programs in teacher training were introduced. Textbooks, although very limited, were produced that reflected the culture of Mozambique. Most are in Portuguese, which remained the official language of the country, in part because none of the multitude of different cultural groups dominates.

German educational policy in Africa. Well before Chancellor Otto von Bismarck had granted a charter to the German Colonial Society in 1885, German missionaries, both Protestant and Catholic, were operating in various regions of western, central, and eastern Africa—from 1840 in Mombasa (now in Kenya), from 1845 in Cameroon, from 1847 in Togo, and from 1876 in Buganda (now Uganda) and in Mpwapwa and Tanga (now in Tanzania). Instruction was everywhere conducted in the local languages, which were objects of study by numerous missionaries and by eminent scholars.

Missionary schools in German areas

On the eve of World War I, more than 95 percent of the schools in German Africa were operated by religious groups. In the southwestern part of the continent the government did not establish any schools at all, relying completely on missionary activity. (In eastern Africa, however, where the large Muslim population was unwilling to send its children to schools managed by Christian religious groups, the government did assume a more active educational role.) To assist the missions, the government granted aid to those schools that met requirements based on specific government needs that changed with time. An example of this sort of aid was the fund founded in 1908 for the dissemination of the German language. The missions had not previously been required to include German in the curriculum but were now forced to do so in order to receive money from the new fund. The language problem was a persistent one and was handled differently in different colonies. In eastern Africa, Swahili was recognized as a language and emphasized in the lower schools, thus providing a lingua franca for the entire area. The government attempted a similar policy with Ewe in Togo and Douala in the Cameroons, but, in southwestern Africa, German was the language of instruction.

Throughout the literature on German educational policy in the African colonies, there is a continued emphasis on the necessity for vocational education and practical work. The missions, however, were more interested in establishing schools providing general education, and lay German educators took a dualistic approach to African education, emphasizing both practical and academic studies.

The absorption of German colonies by England and France after World War II eradicated most of the German influence in education. However, the German insistence on Swahili in German East Africa left that area far more unified linguistically than any other colonial area.

Education in British colonies and former colonies. In the British colonies, as elsewhere, religious missions were instrumental in introducing European-type education. The Society for the Propagation of the Gospel in Foreign Parts, the Moravian Mission, the Mission of Bremen, the Methodists, and Roman Catholic missionaries all established themselves on the Gold Coast (Ghana) between 1820 and 1881, opening elementary schools for boys and girls, a seminary, and eventually a secondary school (in 1909). In Nigeria, Protestant missions were opened at Badagry, Abeokuta, Lagos, and Bonny from 1860 to 1899, and the Roman Catholic missions entered afterward and opened the first catechism, primary, secondary, and normal schools. In Uganda and Kenya the Church Missionary Society, the Universities Mission to Central Africa, the White Fathers, and the London Missionary Society opened the first mission schools between 1840 and 1900.

The first official lay schools came later and for a long time constituted a weak minority. In 1899 in Nigeria, for instance, only 33 of the 8,154 primary schools were government-run and only nine of the 136 secondary schools and 13 of the 97 normal schools. Similarly in the Gold Coast in 1914 the government was responsible for only 8 percent of the schools. In Kenya and Uganda, all schools were conducted by missions. Not until 1922 did the British government assume some responsibility for education in Uganda by opening the first government technical school at Makerere (the future Makerere University College). Only in territories seized from the Germans in World War I did the British take over the administration of existing government schools. Generally the British preferred to leave education to missions, which were given variable financial aid, usually from local and inadequate sources.

British efforts at reform in the 1920s and '30s

Following the publication of critical reports in 1922 and 1925, when there was growing uneasiness among the Africans, the missions, the governors, and the administrators, the necessity of a precise policy on education was imposed on the British authorities. In 1925 an Advisory Committee on Education in the Colonies, created in 1924 and presided over by William Ormsby-Gore, published an important report. The ideas, principles, and methods formulated in this document covered the matters involved in defining a policy; namely, the encouragement and control of private educational institutions, the cooperation by the governmental authorities with these institutions, and the adaptation of education to the traditions of the African peoples. Special importance was attached to religious and moral instruction, to the organization and status of education services, to subsidies to private schools, to instruction in the African languages, to the training of native teachers, to the inspection of schools and the upgrading of teachers, to professional training and technique, and to the education of young girls and women. The structure of an educational system, at the most advanced stage, was to consist of an elementary education (generally six years), diversified middle and secondary education (four to six years), technical and professional schools, specialized schools of higher education, and adult education.

In practice, subsequent British policy in black Africa was far from the recommendations of the Ormsby-Gore committee. The subsidies to mission schools were subject to regulations that varied from one colony to another and paid insufficient attention to the character of the education. The development of instruction, especially secondary, was generally curbed, and various local associations and numerous organizations therefore arose to promote the expansion of education. The colonial governments exerted real effort only on behalf of schools that trained subaltern cadres for administration and commerce (mostly schools for the children of chiefs and prominent persons and the colleges at Makerere and Achimota). Government-sponsored secondary education began only after 1930 in the Gold Coast, only in a conditional manner in 1933 at Makerere College in East Africa, and only after 1935 in Nigeria. In Uganda no complete secondary school existed until 1945.

The Advisory Committee reports published in 1935 and 1944 raised the same questions and the same fundamental themes, indicating that the government still was playing an insufficient role in education. Development was primarily a result of the efforts of missions, of various private local or foreign institutions, and of local indigenous authorities. After World War II the different sectors of education were developed with the growing participation of Africans, who were gaining more autonomy. Secondary education expanded. Institutions of higher learning were improved and increased in number: university colleges were established at Accra and Ibadan in 1948, at Makerere in 1949, and at Khartoum in 1951; a College of Technology (later, University of Science and Technology) was founded in Kumasi in 1951; and the Royal Technical College of East Africa (later, University College) was founded in Nairobi in 1954. Beginning in 1950, development plans for the various colonies—Ghana (the Gold Coast), Nigeria, Sierra Leone, Kenya, Uganda, and Tanganyika—contributed to educational progress.

Upon achieving home rule and then independence, the new African states born of the old British colonies were inheritors of an educational system that, though better than that of the other African states, was still a cause for concern. In most states (Ghana, Kenya, and Malawi being the only exceptions) less than 40 percent of the population had a primary education. Secondary education was even less widespread, Ghana being the only country in which it exceeded 10 percent. Higher education existed in urban centres but still in an embryonic state. Other serious obstacles to the ultimate development of education for all the people included the diversity of organizations and institutions responsible for education, the necessity for students to pay fees, and the complexity of the legislation in force.

Educational improvements after independence

Every one of the various countries set out to improve education. They offered subsidies to private schools, extended supervision over them, and regulated their tuition. They increased the number of primary and secondary schools offering free or partly free instruction and created numerous institutions of higher learning, such as the universities of Cape Coast in Ghana, of Lagos, of Ifẹ̀, and of Ahmadu Bello in Nigeria, and the universities of Dar es Salaam in Tanzania, Nairobi in Kenya, and Makerere in Uganda. The educational systems inherited from colonial rule were racially integrated and subjected to "Africanization." The rate of educational growth is not spectacular, however. Moreover, the place made for African languages in primary education seems everywhere to have been eclipsed by English, the official language—in spite of the widespread use of African languages in the mass media.

Education in French colonies and former colonies. As elsewhere in Africa, mission schools were the first to be established in French colonies. Although public or official schools appeared in Senegal between 1847 and 1895, the first such schools in Upper Senegal, Niger, Guinea, the Ivory Coast, and Dahomey were begun only from 1896 on.

Only after 1900, with the organization of the federated colonies of French West Africa and French Equatorial Africa, was there a French colonial policy on education. By decree in 1903, education in French West Africa was organized into a system of primary schools, upper primary schools, professional schools, and a normal school. Two further reorganizations followed decrees in 1912 and 1918, and important schools were established—the St. Louis Normal School in 1907 (transferred to Gorée in 1913), the School for Student Marine Mechanics of Dakar in 1912, and the School of Medicine of Dakar in 1916. The educational organization that remained in force in French West Africa from 1924 until 1947 included a system consisting of primary instruction for six years (regional urban schools), of intermediate–higher primary education given in upper primary schools and in professional schools (generally one for each colony), and at the top the federal schools—two normal schools, a school of medicine and pharmacy, a veterinary school, a school for marine mechanics, and a technical school. The two schools for secondary education, both in Senegal (the Faidherbe State Secondary School of St. Louis and Van Vollenhoven State Secondary School, at Dakar), were reserved for Europeans and those rare Africans having French status.

Total enrollment in French West African schools rose from 15,500 in 1914 to 94,400 in 1945. The number of students in the higher primary schools grew in the same period only from 400 to 800 or 900. (The area's total population in 1945 was almost 16 million.)

French educational policy in Africa

Educational policy was stated frankly in the official statements of governors general:

> Above all else, education proposes to expand the influence of the French language, in order to establish the [French] nationality or culture in Africa (*Bulletin de l'Enseignement en AOF*, No. 45, 1921); Colonial duty and political necessity impose a double task on our education work: on the one hand it is a matter of training an indigenous staff destined to become our assistants throughout the domains, and to assure the ascension of a carefully chosen elite, and on the other hand it is a matter of educating the masses, to bring them nearer to us and to change their way of life. (From *Bulletin de l'Enseignment en AOF*, No. 74, 1931.)

After World War II, all inhabitants of the newly established "French Union" became citizens in common who

were represented in the French Parliament. This political policy carried over into education, which became even more assimilationist: the old higher primary schools, for instance, became classical and modern secondary schools on the French model. An Investment Fund for Economic and Social Development provided financial and developmental aid to education—to the extent that primary enrollments rose to 156,000 in 1950 and to 356,800 in 1957, and higher primary enrollments rose to 5,800 in 1950 and to 14,100 in 1957. Technical and professional education also expanded, from 2,200 students in 1951 to 6,900 in 1957. Scholarships, awarded by the central government, the colonies, and local groups, enabled an increasing number of African youths to pursue higher education in France. In Senegal in 1950 the first French West African university was established, the Institute for Higher Studies, later called the University of Dakar, followed by those of Abidjan and Brazzaville.

In 1957 and 1958, when the colonies achieved autonomy and then a kind of commonwealth status within the new French Community established by the Gaullist constitution, education began a more intensive development, at least quantitatively. More primary and secondary schools were opened; teacher training was accentuated; and more scholarship students went to France. Within three years, after the French African countries had achieved full independence, this upgrading of education accelerated. Curricular reforms, however, were slow. Although such countries as Guinea, Mali, and the Congo (Brazzaville) introduced such reforms as the Africanization of history and geography, generally the traditional French system persisted, and courses were taught in French. The so-called ruralization of primary education—that is, the spread of education beyond the towns—proceeded under the aegis of the governments and French educational officials.

The rise in the number of primary students was spectacular at first: between 1955 and 1965, for instance, the percentage of primary-age children enrolled in school increased in Guinea from 5 to 31, in Senegal from 14 to 40, in Niger from 2 to 12, and in Chad from 5 to 30. Such progress, however, depended on recourse to unqualified teaching personnel. Since then, some countries have successfully continued programs of rapid educational expansion (the percentage of primary-age children enrolled in school rose to 28 in Niger and to 55 in Senegal in 1985). Progress was slower in other countries (in 1984 the percentage had risen only to 38 in Chad), and in some areas enrollment even declined (the percentage dropped to 30 in Guinea in 1985). Also, in the former French areas, the number of students attaining a higher education remained among the lowest in Africa.

Education in Belgian colonies and former colonies. As elsewhere and perhaps more than elsewhere, the Catholic and Protestant missions played the prime role in the development of education in the Belgian Congo (today Congo [Kinshasa]; called Zaire from 1971 to 1997) and in Ruanda-Urundi (the present states of Rwanda and Burundi). In the period before 1908, when the Belgian king Leopold II treated the Congo as virtually his private preserve, the missions had assumed an unofficial responsibility for education. After 1908, when the Belgian parliament assumed control of the Congo, the Roman Catholic mission schools were given a privileged official status, with government subsidies, while the Protestant schools, though financially unassisted, were also officially authorized to operate. Throughout the colonial period the overwhelming majority of schools were missionary, and until 1948 the systems were limited to two-year primary schools, three-year middle schools, and a sprinkling of technical schools for training indigenous cadres. In 1948 the Belgian government issued a new plan entitled "Organization of Free Subsidized Instruction for the Indigenous with the Assistance of Christian Missionary Societies," which promised more diversification in primary education (both vocational and secondary-preparatory) and, more radically, recommended the establishment of secondary schools that would prepare the Congolese for higher education.

Missionary schools in Belgian areas

In 1962 the government of the newly independent Congo proceeded with a reform of the old educational system: the first primary degree was standardized and its length extended from two or four years to six years; and pupils were to take a common primary course prior to their orientation toward general, normal, or technical secondary education or toward professional education. Numerous specialized schools of higher education were created: the National Institute of Public Works and Construction, the School of Civil Engineers, the National Institute of Mines, the Higher Pedagogical Institute, the Higher Institute of Architecture, and the National School of Administration. To the already existing Lovanium University of Kinshasa (founded in 1954) and the Official University of the Congo (founded in 1955 in Lubumbashi) there was added the Free University of the Congo (founded in 1963 in Kinshasa). Although less pronounced, an analogous evolution characterized Burundi and Rwanda.

By 1970 the Congo's school and university infrastructure was among the best in Africa. Then, from 1974 to 1977, the country, then called Zaire, went through a period of intense nationalism. Zairians with Christian names were ordered to change them to African names. Foreign-owned businesses were sold to Zairian citizens. All schools were nationalized, and mission schools were made state schools. A program of accelerated teacher training was instituted. The old universities were combined with the National University of Zaire. The economic chaos that resulted from these moves caused the government to quickly rescind its plans, however. Businesses were returned to foreign owners in 1977. The church schools were reinstated in 1976, and the universities once again separated in 1981, but the economic and political upheaval was disastrous for the educational system.

Problems and tasks of education in contemporary Africa. The independent African states face numerous problems in implementing an educational policy that will encourage economic and social development. Pedagogical problems and economic and political problems all intermix. The difficulties confronting most governments, however, are basically political.

African educational crisis

Numerical increases in school enrollments, though occasionally spectacular, fail to correspond to the legitimate aspirations of the people or even, more modestly, to the initial objectives fixed by the governments themselves. The Conference of Nairobi in July 1968 viewed as rather alarming the lack of progress in education and literacy in the context of growing populations. Increasing emphasis has been placed on improving and expanding vocational-technical, adult, and nonformal programs of education. There has also been concern about the financial difficulties of the different states, the unsuitability of current educational systems to local needs, the waste and duplications in primary and secondary education, and the insufficient liaison between educational policy makers and the planners of economic and social development. In short, an educational crisis has developed and ripened in black Africa.

(A.M./Da.G.S.)

The Middle East. Modern education was introduced into the Middle East in the early 19th century through several channels. Rulers in both Egypt and the Ottoman Empire (1300–1922) established new military and civilian schools to teach people the skills required to build modern states. In Iran, too, rulers opened new schools, though on a much smaller scale. Many missionary and foreign schools were also established, especially in the Levant. These modern institutions affected only a small percentage of the people, however; the mass continued to receive a traditional education in the Islāmic schools.

Colonialism and its consequences. Following World War I and the destruction of the Ottoman Empire, new states emerged, which—with the exception of Turkey—fell under French or British control. Although the new nations inherited educational institutions of various size, each needed to build a new educational system, either from scratch or by expanding a small existing system. Each country sought to use education to provide the skilled manpower required for national development and to socialize its diverse population into feeling loyal to the new state. Educational expansion was pursued everywhere, but the particular pattern of change was profoundly affected by the nature of the political regime, particularly by colonial

Aims of colonial educational policy

status. In Lebanon, Syria, Tunisia, Morocco, and Algeria educational policy reflected French interests. In Egypt, Jordan, Palestine, and Iraq, British policy prevailed. Both colonial powers shared similar goals: to preserve the status quo, train a limited number of mid-level bureaucrats, limit the growth of nationalism, and, especially in the case of France, impose its culture and language. Accordingly, they limited educational expansion, particularly at the higher levels, even though the demand continued to grow.

Private, foreign, and missionary schools were favoured everywhere as alternatives, for the upper classes, to the inadequate public schools. The public systems were centrally administered. Their curricula were usually copied from the British or the French and thus were of limited relevance to local needs; the numbers and quality of teachers were seldom adequate; and dropout rates were high. Few modern schools were to be found in the Arabian Peninsula. Only in Lebanon and in the Jewish community in Palestine (which developed its own educational system) were significant numbers of students enrolled in modern schools. Elsewhere, only a small percentage of the populace (including a few women) received a modern education.

Upon achieving independence, the Middle Eastern nations nationalized the private schools, which were regarded as promoting alien religions and cultures, and greatly expanded educational opportunities, especially at the upper levels. Egypt, for example, in 1925 nationalized a small, poor private institution (founded in Cairo in 1908) and made it into a national university and subsequently opened state universities in Alexandria (1942) and 'Ain Shams (1950). The newly independent countries also sought to equalize educational opportunities. Iraq provided free tuition and scholarships to lower-class students. Syria, in 1946, made primary education free and compulsory. Jordan enacted a series of laws calling for free and compulsory education and placed strict controls on foreign schools, especially the missionary ones.

Despite their importance, these reforms did not transform education. The schools in Egypt, Iraq, Syria, and Jordan, for example, continued to be characterized by rigidity, formalism, high dropout rates, and limited relevance to national needs. Moreover, rapid population increases often offset the educational gains, especially in Egypt. Egypt also could not overcome the existing fragmentation of its educational system. Its modern system was divided into schools for the masses and schools that provided access to the higher levels for the elite. Both types coexisted uneasily with the traditional Islāmic schools, which ran the gamut from rudimentary primary schools to the venerable al-Azhar University.

Educational reforms under Atatürk

Countries with strong nationalist leaders were more successful in modernizing education. Mustafa Kemal Atatürk of Turkey, who was determined to create a modern state, initiated a dramatic program of social and cultural change in which education played an important role. He closed the religious schools, promoted coeducation, prepared new curricula, emphasized vocational and technical education, launched a compulsory adult education project, established the innovative Village Institutes program to train rural teachers, and, in 1933, reorganized Istanbul University into a modern institution staffed mainly by refugees from Nazi Germany. Later, Istanbul Technical University also reorganized and Ankara University was established.

Reza Shah Pahlavi followed similar policies in Iran, albeit to a lesser degree, for he was a reformer rather than a modernizer and ruled a country that had been largely isolated from modern influences. He integrated and centralized the educational system, expanded the schools, especially the higher levels, founded the University of Tehrān (1934), sent students abroad for training, moved against the Islāmic schools, promoted the education of women, and inaugurated an adult education program. Nevertheless, the Iranian educational system remained small and elitist.

After World War II new leaders came to power, including Gamal Abdel Nasser in Egypt in 1952, Habib Bourguiba in Tunisia when it became independent in 1956, and the revolutionary government that deposed the monarchy in Iraq in 1958. They began to make major administrative and social reforms and adopted educational policies similar to those of Atatürk. Bourguiba's reform plans called for universal primary education, an emphasis upon vocational training, expansion of the higher levels, incorporation of the Qur'ānic schools into the modern system, and the promotion of women's education.

Problems of Arabicization in French areas

Tunisia, like the other French possessions in North Africa, had to face yet another educational challenge—nationalizing a system that was designed to socialize students into French culture. Arabicization, the substitution of Arabic for French as the language of instruction and of texts and syllabi representing Arab concerns for ones developed to meet French needs, presented many difficulties. Most teachers were qualified to teach only in French, and appropriate texts were not available. When Algeria and Morocco gained independence from France they adopted similar policies and encountered the same problems, which have been expensive and difficult to overcome. By the 1980s the Arabicization process remained incomplete; in all three countries, some instruction was still being given in French.

Egypt's President Nasser also sought to transform society and culture. He integrated and unified the Egyptian educational system by bringing the religious schools under secular control and by transforming al-Azhar University, long a centre of Islāmic learning, into a modern institution. The old elementary system, which provided access to further education only for urban students, was abolished, and major curricular and other reforms were implemented. All public education was made free, and strong efforts were made to universalize primary education, to upgrade technical and vocational education, and to improve the quality of education generally.

These important reforms did not always produce the anticipated results. Nasser failed to devise a coherent educational strategy that paid adequate attention to the systemic implications and the fit between educational expansion and developments in other sectors. Tunisia, too, despite large investments, was unable to coordinate educational expansion with the needs of the economy.

The contemporary scene. Every modern Middle Eastern state is striving to create an educational system that promotes economic growth and provides equal educational opportunities. In addition, the Arab states wish to promote cultural unity. In 1957 Egypt, Syria, and Jordan replaced the educational structures that had been established by the colonial powers with a common one consisting of six years of primary school, three years of middle school, and three years of secondary school. Most of the Arab states have since followed this pattern, although the length of the school year varies from country to country. The Arab systems also differ in the emphasis they place on certain subjects, especially religious instruction and Arabic, which occupy an especially prominent place in Saudi Arabian schools.

Turkey, Iran, and all the Arab states except Lebanon have another feature in common. Education to the secondary level in these countries is planned and administered by a central ministry. These ministries are generally characterized by administrative weaknesses that severely handicap the provision of education. University education may also be the responsibility of the ministry or, as in Turkey, Iraq, and Egypt, may be supervised by a separate body.

Educational planners have usually attained, or surpassed, their quantitative targets for academic schooling. School enrollments and literacy rates have risen substantially throughout the Middle East. These gains, however, have been at least partly offset by rapidly growing populations. In Egypt the absolute number of illiterates has increased, and Turkey's goal of universalizing primary education was not achieved until the 1980s. Some governments, notably those of Iraq, Algeria, Kuwait, Egypt, Iran, and Turkey, have initiated adult literacy programs, with varying degrees of success.

Inequalities in education

Planners have been less successful in achieving their other goals. Despite great efforts, primary and secondary education everywhere retain certain traditional features. Inequalities remain in such areas as rural and urban access to education and women's education. Although female school enrollment ratios have risen throughout the Mid-

dle East, they remain considerably lower than male ratios in every country except Jordan, Lebanon, and Israel, which have achieved almost universal elementary literacy. Moreover, at the higher levels of education, the percentage of women students becomes progressively lower. Many countries, especially Egypt and Tunisia, have made strenuous efforts to overcome the economic and cultural factors that limit women's education, but their experience demonstrates how difficult it is to do so.

Qualitative goals have also been difficult to achieve. Financial, human, and physical resources have not kept pace with growing enrollments. As a result, the quality of primary and secondary education has suffered. Split shifts, crowded classrooms, serious shortages of qualified teachers, and inadequate textbooks and curricula are common problems. The examination system used by most countries to determine which students may advance to the next level of education also hurts educational quality. Most experts agree that the examination system does not provide a reliable indication of student ability. Furthermore, they feel that it reinforces tendencies of traditional scholarship toward memorization and conformity in the classroom.

Various innovations have been introduced in an attempt to remedy these shortcomings. One of the most important is the nine-year basic education program, which seeks to provide all children between the ages of six and 15 years with an integrated study program that is practical, does not involve examinations, and prepares students to function in a changing environment. It has been widely implemented in Egypt and has been introduced in Tunisia and Syria.

University education in the Middle East

The Middle Eastern nations have also been confronted by serious problems at the university level. Because a degree was widely regarded as a passport to elite status, the demand for higher education grew dramatically. Every government sought to limit the flood of entrants through examinations but managed only to slow, not stop, the growth, which far outpaced projections and resources. To help accommodate the surplus, Egypt and Turkey established programs of "external students" and open universities, which allow students to take courses at home at their convenience through the Internet, radio and television broadcasts, recordings, and other techniques. Every year more and more students of lower-class backgrounds receive a university education, but the entrance examinations tend to limit admissions to the most desirable faculties (medicine and engineering) to students of elite backgrounds. The rising number of graduates with unneeded skills has in turn aggravated problems caused by lack of coordination between education and employment needs. Governments face the difficult task of absorbing poorly prepared graduates into the work force while they try to find qualified managers, technicians, and skilled workers. Moreover, from independence there was a strong populist tendency in some Arab countries to guarantee employment to all university graduates. This led to bloated government bureaucracies. Fiscal restructuring in the 1980s and '90s led to numerous cutbacks in government hiring with attendant societal angst.

The development of higher education has been adversely affected by political considerations. Most Middle Eastern countries have never accepted the principle of academic freedom in the Western sense. Turkey, Lebanon, and Israel are prominent exceptions, but even Lebanese and Turkish universities have been subject to political control.

In Turkey the universities became so politicized in the 1970s that ideology influenced many aspects of university life. After the military coup of 1980, the government proceeded to limit university autonomy and to eliminate political activism. Iran and most Arab countries have always been ruled by more or less authoritarian regimes that regard universities as potential sources of opposition. The governments in these countries try to use schools and colleges to disseminate the prevailing ideology. Hence scholars often emigrate and those who remain at home are compelled to teach and research in ways that will not create difficulties.

Efforts to increase vocational and technical training have not been very successful because of the continuing appeal of white-collar careers. In Egypt the government's attempt to channel students into technical and vocational schools yielded mixed results. Enrollments did increase, but the quality and relevance of such education was questioned as authorities considered the costs involved in purchasing expensive equipment and in training and retaining qualified teachers, whose skills enable them to obtain more remunerative positions in industry. The same difficulties prevail in the other Middle Eastern countries, although the World Bank has helped improve conditions in Turkey through the Basic Education Project and other programs that expanded the vocational school network.

Vocational education

Technical training in the agricultural sector is also deficient. There is a shortage of qualified extension agents and other specialists everywhere. Moreover, the bias toward academics means that rural education tends to be neglected, even though the need for agricultural modernization in national development requires that peasants acquire a wide range of skills. Israel is one country where rural education receives the attention that it deserves.

The Islāmic revival. The rapid expansion of modern education and knowledge has produced results that have not been welcomed everywhere. Islām remains, in all Middle Eastern societies, a powerful force, one nurtured by traditional factors disseminated by religious education, which continues to be widely offered in one form or another. Believing that traditional Islāmic values have been eroded by Western knowledge based on erroneous assumptions, numerous Islāmic scholars have called for the creation and diffusion of knowledge within an Islāmic framework. The Iranian revolution and the rise of Islāmic fundamentalist movements demonstrate the power of this appeal. Religiously based polities such as Saudi Arabia and Iran emphasize Islāmic teachings and values in all schools and colleges, and many other states provide more religious education than previously.

Migration and the brain drain. Educational systems have also been affected by the widespread international migration of professionals and skilled workers that characterizes the Middle East. Formerly, the West siphoned off a significant percentage of the skilled manpower from Lebanon, Syria, Turkey, Egypt, and Jordan. Now, large numbers of educated persons have migrated from Turkey, Lebanon, Syria, and especially Egypt and Jordan to the oil-rich states, especially to Bahrain, Kuwait, Libya, Saudi Arabia, Qatar, Oman, Algeria, and the United Arab Emirates. This flow aggravates shortages of skilled workers in many of the exporting countries, especially Jordan, Syria, and Lebanon.

Effects of migration on education and employment

These outflows of human capital stem from educational and economic structures that do not meet the country's labour requirements. This continued loss of workers further reduces existing standards because those qualified to teach the next generation are among those who emigrate. Moreover, the attraction of working abroad is so strong that many persons choose schools and subjects in order to enhance their potential for migration, regardless of the domestic demand. Thus, domestic educational systems have become geared to meet the needs of other societies while domestic employment needs are neglected.

Despite the many problems, it should be emphasized that all the Middle Eastern states have built modern educational systems in the face of considerable difficulties. The importance of education is acknowledged everywhere, and every state is striving to make education more relevant to personal and societal needs, to achieve greater equity, to lower the high wastage rates, and to improve quality.

(J.S.Sz.)

Latin America. The term Latin America is a facile concept hiding complex cultural diversity. This abstraction covers a conglomerate of areas, distinguished by differences not only in the indigenous population base but also in the superimposed nonindigenous patterns—Spanish, Portuguese, French, Dutch, and Anglo-Saxon. In this brief survey, generalizations will be limited to the major Spanish- and Portuguese-speaking groups, which account for the vast majority of the population.

The heritage of independence. At the beginning of the 19th century, the Spanish colonies enjoyed a prosperity that led to optimism, thoughts of independence, and republican rule. In the prolonged struggle for independence,

they were all but ruined, and the change from absolute monarchy to popular democracy was far from easy. The revolutionaries tried to follow the U.S. model, but novel institutions clashed with those of the past; governmental practice did not follow political theory; and the legal equality of the citizens hardly corresponded to economic and educational realities.

Roman Catholicism and education in Latin America

The new governments all considered education essential to the development of good citizens and to the process of modernization. Accordingly, they tried to expand schools and literacy, but they faced two obstacles. Their first was a disagreement over what should form the content of education. Since the time of the Enlightenment, political tyranny and the Roman Catholic church had been blamed for backwardness. Thus, once independence had been achieved, the liberals tried to get rid of the church's privileges and to secularize education. The conservatives, however, wanted to follow traditional educational patterns and considered Catholicism a part of the national character. After decades of confrontation the liberals in many countries managed to make education both secular in character and a state monopoly. In other countries, such as Colombia, by way of a concordat with the Holy See, religious education became the official one.

The second obstacle to educational expansion was a financial one. The new governments lacked the means with which to establish new schools. Thus, they began to import the Lancaster method of "mutual" instruction (so named from its developer, the English educator Joseph Lancaster), which in monitorial fashion employed brighter or more proficient children to teach other children under the direction of an adult master or teacher. Its obvious advantage was that it could accomplish an expansion of education rather quickly and cheaply. Beginning in 1818, it was introduced in Argentina and then in Chile, Colombia, Peru, Mexico, and Brazil. Until well into the second half of the 19th century, it was to be the most widely used system.

Almost all the heroes of independence tried to establish schools and other educational institutions. José de San Martín founded the National Library and the Normal Lancasteriana, a teacher-training school, in Lima; Simón Bolívar established elementary schools in convents and monasteries and founded the Ginecco (1825), known afterward as the Normal Lancasterian School for Women. Bernardino Rivadavia, the first president of Argentina, also stimulated educational development, including the establishment of the University of Buenos Aires. In mid-century, Benito Juárez in Mexico also championed education as the only bulwark against chaos and tyranny.

By the 1870s the liberals had won the day almost everywhere throughout Latin America. Education was declared to be compulsory and free, the lack of teachers and teacher colleges notwithstanding. A program to remedy this situation was launched. Chile paid for the educator Domingo Faustino Sarmiento's travels to the United States and Europe and enabled him to found, on his return in 1842, the Normal School for Teachers. This was the first non-Lancasterian teachers' college and was to be followed in 1850 by the Central Normal School in Lima and in 1853 by the Normal School for Women in Santiago. Countries with more acute educational problems, such as Ecuador, simply imported the Brothers and Sisters of the Sacred Heart and put them in charge of organizing their educational system. During the 1870s and '80s, foreign teachers began to be imported and students were sent abroad. Sarmiento had already called in North American teachers to open his normal schools in the 1860s, and Chile invited Germans for its Pedagogical Institute (1889). Germans and Swiss came to Mexico and Colombia; a number of distinguished Mexican educators were trained by Germans in the Model School in Orizaba. With the foreign professors came new pedagogical ideas—especially those of Friedrich Froebel and Johann Friedrich Herbart—and also new ideologies, foremost among them positivism, which flourished in Argentina, Brazil, Chile, and Mexico.

Administration. With independence, the task of overseeing public instruction fell to the state and local authorities. Fiscal poverty and a lack of trained personnel soon proved them unequal to the task. Furthermore, since most existing schools were confessional and private, the need for intervention by the central authorities to enforce unity became obvious. In 1827 the Venezuelan government established a Subdirectory of Public Instruction, which in 1838 became a directory. Mexico established a General Directory of Primary Instruction in 1833. Soon, some countries decided to assume responsibility for centralization through a ministry for public instruction—Chile and Peru in 1837, Guatemala in 1876, Venezuela in 1881, and Brazil in 1891. Other governments abstained from accepting total responsibility. In Mexico, no ministry was created until 1905 and then only with jurisdiction over the Federal District and territories; even that became a victim of the revolution of 1910. In 1922 a Mexican ministry was reestablished, now in charge of the whole republic and taking up the functions that the states could not fulfill. In Argentina the Lainez Law, decreed in 1905, authorized the National Council of Education to maintain, if need be, schools in the provinces.

Efforts to centralize educational administration

Today, in all countries the control over education is in the hands of a ministry of public education or a similar government unit. Its functions include planning, building, and administering schools, authorizing curricula and textbooks for public elementary and secondary schools, and supervising private ones. In some countries, the states sustain their own educational systems, which the federal government then supplements, but, because of the disparity between city and countryside, these federal governments often have had to shoulder almost the total burden of rural elementary education.

Primary education and literacy. At the time of independence, elementary education consisted of teaching reading and writing, the religious and civil catechisms, and rudiments of arithmetic and geometry. By the second half of the century, it became differentiated between "elementary primary" and "superior primary" education, and the curriculum was enlarged to include the teaching of national language, history, geography, rudimentary natural sciences, hygiene, civics, drawing, physical education, and crafts for boys and needlework for girls. The elementary primary school was increased to five or six years, and the superior primary was to become the secondary school of the 20th century. These educational levels absorbed the greatest part of the governmental efforts and became a means to do away with illiteracy and also to create a concept of citizenship.

Primary instruction was improved by special programs and teacher training, and both benefited from educational influences coming from abroad but also from improvements resulting from the study of national problems. Today, primary-school teachers are trained in teachers' colleges having the status of secondary schools.

Problems of rural and native education

Thanks to solid foundations laid during the 19th century, public education in Argentina and Chile reached a high level of competence. In other countries, because of such factors as a more heterogeneous population, a higher level of demographic growth, and greater geographical barriers, the results of great efforts have been less than impressive. Although all countries have declared primary instruction to be free and compulsory, the situation in reality is rather complex. Whereas, in towns, many children have gone from kindergarten to secondary schools since the beginning of the century, in the rural areas, even today, many schools have only one teacher to handle students of all levels. Furthermore, because many Indian citizens do not understand Spanish, special instruction is required. In the 20th century, governments have established special institutions for Indians. The first such cultural mission was created by the Mexican secretary of education, José Vasconcelos, in 1923. The idea was to send an elementary-school teacher, an expert in trades and crafts, a nurse, and a physical-education teacher to underdeveloped communities, in which, during a limited period, the population would be provided with some general education. The United Nations Educational, Scientific and Cultural Organization (UNESCO) has helped in the training of teachers for these special areas through two regional centres of fundamental education for Latin America (CREFAL), one in

Mexico and the other in Venezuela. Many countries have tried to master the dropout problem by offering at least one free meal a day to those who continue their schooling.

Uruguay, Argentina, and Chile have been able to multiply their schools and thus to provide facilities for their entire population of school age. In other countries, the efforts may be gauged by comparing statistics. In Peru, only 29,900 children went to school in 1845; but there were 59,000 in 1890 and 2,054,000 in 1965. In Brazil, there were 115,000 pupils in 1869; 300,000 in 1889; and 9,923,000 in 1965. In Mexico, there were 349,000 in 1874; 800,000 in 1895; and 7,813,000 in 1969. Unfortunately, the high population-growth rate (2.9 percent) makes it difficult to keep up with the ever-increasing needs.

Fight against illiteracy

Illiteracy has been fought by various means in accordance with the political and socioeconomic situation. Until the middle of the 19th century, illiteracy in Latin America was in excess of 90 percent. Of Brazil's population, only 1.5 percent were literate in 1823. Around the beginning of the 20th century, illiteracy had decreased to 39 percent in Argentina (1908), 50.4 percent in Uruguay (1908), and 68.2 percent in Chile (1895); in other countries it fluctuated between 80 and 98 percent. By 1985 illiteracy was down to 6.0 percent in Argentina, 5.7 percent in Uruguay, 10 percent in Chile, 26 percent in Mexico, 28 percent in Peru, 25 percent in Bolivia, and 26 percent in Brazil. Nations with the greatest illiteracy were Guatemala, with 50 percent, and Haiti, with 77 percent.

Secondary education. During the 19th century, many countries established new secondary schools on the basis of colonial institutions. Thus, in 1821 Argentina converted its College of San Carlos into its College of Moral Sciences. Mexico attempted a total reform in 1833 but would not complete it until 1867 with the founding of the National Preparatory School, which involved reforming the whole system on the basis of positivist philosophy. In Brazil the Royal Military Academy was established in 1810 and the Pedro II College in 1830, but secondary instruction did not prosper until the return of the Jesuits in 1845 and was to be supplemented later by *gimnasios*—that is, *Gymnasien* on the German model. Peru and Venezuela established national colleges, and Chile and Argentina created *liceos* (modeled on the French *lycées*) and, later, national colleges. (The term college in all cases here is used in the continental European sense to refer to secondary institutions, not institutions of higher education.)

Secondary emphasis on university preparation

In all countries (except perhaps Chile), secondary instruction has been considered a preparation for the university. All attempts to make it more formative and practical have failed, in spite of the fact that the government has taken charge. The secondary-preparatory course lasts from five to six years, with a degree of bachelor (*bachillerato*) usually given upon its completion. Its teachers come from the humanities departments of the universities and the superior normal schools (which have existed since 1869 in Argentina, since 1889 in Chile, and in the 20th century in the other countries).

Polytechnical education—industrial, commercial, and agricultural—had been a concern of liberal governments since the end of the 19th century but has developed only recently. Traditional prejudices against practical instruction were overcome only after industrialization began. It has been emphasized only in Argentina, Venezuela, Chile, and Mexico.

Higher education. Imbued with a revolutionary spirit in which education was a vital element, Latin Americans founded 10 universities between 1821 and 1833, among them the University of Buenos Aires (1821). Bolívar himself established two in Peru—Trujillo (1824) and Arequipa (1828). With independence, practically all theological faculties had disappeared, and their position of preeminence was taken over by faculties of law.

Four universities were founded in the 1840s, Chile's among them, and 10 more in the second half of the 19th century. In Mexico the new institutions called themselves institutes of arts and sciences, because the University of Mexico (founded in 1551) was associated with colonialism and had become a favourite target of the liberals. The University of Mexico was suppressed in 1865, not to be reopened until 1910, the year of the revolution. Argentine liberals solved their problem by passing the Avellaneda Law (1885), which allowed only national universities, prohibiting private universities (until the reform of 1955).

In Brazil the plans to open a university in 1823 failed. Several professional schools were established, but the first university opened its doors in 1912 in Paraná. In 1920 the Federal University of Rio de Janeiro was founded.

Almost all higher education in Latin America came to be secular and state-operated. The fact that Latin-American governments, themselves unstable, generally took charge of higher education, however, explains in part its uncertain existence.

Emphasis on state universities

Some colonial religious institutions nevertheless survived. During part of the 19th century, for instance, the University of the Republic in Montevideo maintained its ties with the church. In 1855 the University of San Carlos in Guatemala, through a concordat with Rome, reverted to pontifical status. But, with the exception of the Catholic University in Chile (1888), the Pontifical Catholic University of Peru (1917), and the Javeriana University in Colombia (1931), all religious universities are recent creations. Indeed, today the majority of private institutions are religious or confessional, with the significant exception of some recently established technological institutes (in Monterrey, Mex., and in Buenos Aires). The need for technical education was also recognized by the Mexican government when it founded, in 1936, the National Polytechnical Institute as its second national institution of higher learning, with several branches in the country (regional technological institutes) to serve the particular needs of each region.

Until the 20th century, universities were mainly professional schools. Often, they also supervised primary and secondary education (Uruguay, 1833–37; Chile, 1842–47; Mexico, 1917–21). Today, they also conduct research and try to encourage regional developments. Unofficially, they have sometimes played a role in political life. Since the reform movement for student representation at the University of Córdoba in Argentina in 1918, they have become involved in political controversies. The Mexican government tried to extricate the National University from political strife by giving it autonomy in 1929. Student demonstrations by the late 1960s, however, proved this measure to lack effectiveness.

Higher education has proved to be the best means of furthering social mobility. In spite of this, institutions of higher learning in Latin America have suffered from several handicaps. Foremost is the lack of sufficient funds, which usually results in poor research facilities. Second, both students and professors are generally engaged only half-time. This increases the dropout rate and decreases performance. Thus, most highly qualified professionals are trained abroad. At the same time, both the political situation and economic pressures have induced an exodus of the most highly educated Latin Americans to the United States.

In 1985 there were more than 1,500 institutions of higher learning in Latin America. Brazil, Mexico, Argentina, and Colombia had the highest numbers of university students, but, on the basis of the number of students per population, Argentina was first, distantly followed by Uruguay, Cuba, Chile, Colombia, Mexico, and Brazil.

Reform trends. Although most of the Latin-American countries achieved nominal independence in the 19th century, they remained politically, economically, and culturally dependent on U.S. and European powers throughout the first half of the 20th century. By 1960, many viewed this dependency as the reason for Latin America's state of "underdevelopment" and felt that the situation could best be remedied through educational reform. The most general reform movement (*desarrollista*) simply accepted the idea of achieving change through "modernization," in order to make the system more efficient. The Brazilian educationist Paulo Freire, however, advocated mental liberation through self-consciousness, a view that was influential in the 1960s and '70s throughout Latin America. Because political dictatorship prevailed through the 1960s and part of the 1970s in many countries, authoritarian

pedagogy became the practice, especially in Chile. In the 1980s the deep economic crisis in Latin America proved to be the greatest influence on education, obstructing all renovation or modernization of public education.

(J.Z.V.)

Historical background of modern Southeast Asian education

Southeast Asia. Indigenous culture, colonialism, and the post-World War II era of political independence influenced the forms of education in the nations of Southeast Asia—Myanmar (Burma), Kampuchea (Cambodia), Indonesia, Laos, Malaysia, the Philippines, Singapore, Thailand, and Vietnam.

Before AD 1500, education throughout the region consisted chiefly of the transmission of cultural values through family and community living, supplemented by some formal teaching of each locality's dominant religion—animism, Hinduism, Buddhism, Taoism, Confucianism, or Islām. Religious schools typically were attended by boys living in humble quarters at the residence of a pundit who guided their study of the scriptures for an indeterminate period of time.

With the advent of Western colonization after 1500, and particularly from the early 19th to mid-20th century, Western schooling with its dominantly secular curriculum, sequence of grades, examinations, set calendar, and diplomas began to make strong inroads on the region's traditional educational practices. For the indigenous peoples, Western schooling had the appeal of leading to employment in the colonial government and in business and trading firms.

After World War II, as all sectors of Southeast Asia gained political independence, each newly formed nation attempted to achieve planned development—to furnish primary schooling for everyone, extend the amount and quality of postprimary education, and shift the emphasis in secondary and tertiary education from liberal, general studies to scientific and technical education. Although indigenous culture was still learned through family living and traditional religion continued to be important in people's lives, most formal schooling throughout Southeast Asia had become predominantly of a Western, secular variety.

Schooling in all of these countries was organized in three main levels, primary, secondary, and higher. In addition, nursery schools and kindergartens, operated chiefly by private groups, were gradually gaining popularity. The typical length of primary schooling was six years. Secondary education was usually divided into two three-year levels. A wide variety of postsecondary institutions offered academic and vocational specializations. Beginning in the 1950s, nonformal education to extend literacy and vocational skills among the adult population expanded dramatically throughout the region. Most of the nations were committed to compulsory basic education, typically for six years but up to nine years in Vietnam. However, by the close of the 1980s, the inability of governments to furnish enough schools for their growing populations prevented most from fully realizing the goal of universal basic schooling.

In each nation a central ministry of education set schooling structures and curriculum requirements, with some responsibilities for school supervision, curriculum, and finance often delegated to provincial and local educational authorities. Government-sponsored educational research and development bureaus had been established since the 1950s in an effort to make the countries more self-reliant in fashioning education to their needs. Regional cooperation in attacking educational problems was furthered by membership in such alliances as the Southeast Asian Ministers of Education Organization (SEAMEO) and the Association of Southeast Asian Nations (ASEAN).

Problems which most Southeast Asian education systems continued to face were those of reducing school dropout and grade-repeater rates, providing enough school buildings and teachers to serve rapidly expanding numbers of children, furnishing educational opportunities to rural areas, and organizing curricula and the access to education in ways that suited the cultural and geographical conditions of multiethnic populations.

Myanmar (formerly Burma). The indigenous system of education in Myanmar consisted mainly of Buddhist monastic schools of both primary and higher levels. They were based on (1) the moral code of Buddhism, (2) the divine authority of the kings, (3) the institution of *myothugyi* (township headmen), and (4) widespread male literacy. The Western system was established after the British occupation in 1886. The new system recognized women's right to formal education in public schools, and women began to play an increasingly important role as teachers. The Government College at Rangoon and the Judson College established in the 19th century were incorporated as the University of Rangoon under the University Act of 1920.

Buddhist and Socialist influence in Myanmar

Following independence in 1948, the country experienced more than a decade of political instability until a coup d'état in 1962 brought a strongly centralized socialist government to power. Subsequently, marked improvements in education occurred. Science was emphasized along with general academic subjects, civic education, and practical arts. Primary-school attendance for children ages five through nine became free where available. From 1965 to 1985 enrollments increased in primary schools from two to five million, in secondary schools from 503,000 to 1.25 million, and in higher education from 21,000 to 189,000.

Malaysia and Singapore. The Malay States, Singapore, and sectors of North Borneo were British colonies until reorganized as the nation of Malaysia in 1963. Singapore left the coalition in 1965 to become an independent city-nation. As a result, while Malaysia and Singapore share common educational roots, their systems have diverged since 1965.

The language issue in Malaysia and Singapore

Under British rule, the most significant feature of education on the Malay peninsula was the structuring of primary schools in four language streams—Malay, Chinese, English, and Tamil. Students in the English stream enjoyed favoured access to secondary and higher education as well as to employment in government and commerce. After 1963 Malaysian leaders sought to indigenize and unify their society by adopting the Malay language as the medium of instruction in schools beyond the primary level and by teaching English only as a second language. In contrast, the government of Singapore urged everyone to learn English, plus one other local tongue—Chinese, Malay, or Tamil. Thus, in both nations the learning of languages became a critical issue in people's efforts to gain access to socioeconomic opportunity and in political leaders' attempts to unify their multiethnic populations.

Efforts to popularize schooling in Malaysia and Singapore were notably successful. By the early 1980s, 93 percent of all Malaysian children ages six to 11 attended primary school, with nearly 90 percent of primary-school graduates entering lower-secondary school. By 1968, all primary-age children in Singapore were in school. In both countries, secondary- and higher-education enrollments continued to increase rapidly. Both nations were well supplied with school buildings, textbooks, and trained teachers.

Indonesia. From AD 100 to 1500 the Indonesian aristocracy adopted Hindu and Buddhist teachings, while education for the common people was provided mainly informally, through daily family living. Islām, introduced into the archipelago around 1300, spread rapidly in the form of Qur'ān schools, which have continued through the 20th century, though in diminishing numbers. The first few schools on Western lines were established by Portuguese and Spanish priests in the 16th century. As the Dutch colonialists gained increasing control over the islands, they set up schools patterned after those in Holland, primarily for European and Eurasian pupils. In 1848 the Dutch East Indies government officially committed itself to providing education for the native population. However, even though the amount of education for indigenous islanders increased over the following century, Western schooling under the Dutch never reached the majority of the population.

After Indonesians gained independence from the Dutch in 1949, they sought to provide universal elementary schooling and a large measure of secondary and higher education. Progress toward this goal after 1950 was rapid, despite the challenge of an annual population growth rate of around 2.3 percent. Enrollments over the 1950–1985 period increased from five million to 30 million at the

elementary level, from 230,000 to 7.5 million at the secondary level, and from 6,000 to one million at the tertiary level. Although the Indonesian population was 90 percent Muslim, three-fourths of the nation's schools were of a Western secular variety. The remaining one-fourth were Islāmic schools required to offer at least 70 percent secular studies and no more than 30 percent religious subjects. This ratio reflected the government's efforts to use the schools for preparing manpower for socioeconomic modernization, as guided by a sequence of five-year national development plans.

Philippines. The pre-Spanish Philippines possessed a system of writing similar to Arabic, and it was not uncommon for adults to know how to read and write. Inculcation of reverence for the god Bathala, obedience to authority, loyalty to the family or clan, and respect for truth and righteousness were the chief aims of education. After the Spanish conquest, apart from parochial schools run by missionaries, the first educational institutions to be established on Western lines were in higher education. The Santo Tomás College, established in 1611 and raised to the status of a university in 1644–45, served for centuries as a centre of intellectual strength for the Filipino people. Educational growth, however, was slow, mainly because of lack of government support.

Spanish and American influences in the Philippines

With the advent of American rule, the stress laid on universal primary education in the policy announced by U.S. President William McKinley on April 7, 1900, led to a rapid growth in primary education. A number of institutions of higher education were also established between 1907 and 1941, including the University of the Philippines (1908). Private institutions of higher education, however, far outnumbered the state institutions, thus indicating a trend that remains a characteristic feature of the system of higher education in the Philippines.

The new Republic of the Philippines emerging after World War II launched a series of national development plans that included components aimed at the renovation and expansion of education to promote socioeconomic modernization. Over the period 1948 to 1997, enrollments rose in primary schools from four million to twelve million and in secondary schools from 424,000 to 4.9 million. By the late 1990s, 2 million students were in the nation's more than 1,000 higher-education institutions. More than 95 percent of primary pupils and 41 percent of secondary students attended public schools, while the remainder attended private institutions.

Thailand. The traditional system of education in Thailand was inspired by the Thai philosophy of life based on (1) dedication to Theravāda Buddhism, with its emphasis on moral excellence, generosity, and moderation, (2) veneration for the king, and (3) loyalty to the family. The beginning of the present system of education can be traced to 1887, when King Chulalongkorn set up a department of education with foreign advisers, mostly English educationists. The process of Westernization of education was strengthened with the establishment of a medical school in 1888, a law school in 1897, and a royal pages' school in 1902 for the general education of "the sons of the nobility." It was converted into the Civil Service College in 1910.

The Thai philosophy

The abolition of the absolute monarchy after the 1932 revolution stimulated the government to increase educational provisions at all levels, particularly for training specialists in higher-learning institutions. Beginning in 1962, the nation's series of five-year development plans assigned educational institutions a crucial role in manpower preparation. The government supervises all educational institutions, public and private. Financing education is primarily a government responsibility, supplemented by the private sector. Thai is the language of instruction at all levels, with English taught as a second language above grade four.

By the mid-1990s there were more than 6 million pupils (over 90 percent of the age group) enrolled in the compulsory six-year elementary schools, 3.1 million in the six years of secondary schooling, and 1.2 million in the nation's 31 registered universities and colleges.

Cambodia. For nearly four centuries before the advent of the French in 1863, the educational system in Cambodia grew up around Theravāda Buddhism, which became the established religion toward the end of 1430 under Thai influence. In 1887 Cambodia became a part of the French Indochina Union and did not achieve complete independence until 1954. Pagoda schools, imparting education at the primary level, were remodeled and integrated into the primary school system administered by the Ministry of Education.

Indo-Chinese education under colonialism and war

Civil war throughout the 1970s disrupted education until Vietnamese forces overthrew the Khmer Rouge government in 1979. By the late 1990s schools had a total enrollment of over 2.3 million throughout the four-year primary and five-year secondary structure. Secondary schools and the country's few higher-education colleges were still in a state of rebuilding. Much of the teacher-training was in the form of short courses, and nonformal adult literacy classes multiplied at a rapid pace.

Laos. The pagoda school was the main unit of the traditional educational system in Laos. Efforts toward modernization came in the wake of the country's becoming a French protectorate in 1893 and finally after its inclusion in 1904 within the French Indochina Union. The medium of education was changed to French when the French Education Service was created.

In 1975, after 30 years of uninterrupted revolution, a socialist government was established and schooling was accorded high priority. By the late 1990s, nearly 800,000 students were enrolled in four-year elementary schools, 180,000 in five-year secondary schools, and 12,000 in higher-education institutions.

Vietnam. Long Chinese domination over the emperors of Vietnam resulted in strong Confucian and Taoist influences on the Vietnamese educational system, though it centred on Buddhism. The establishment of French rule, commencing with the occupation of Saigon (now Ho Chi Minh City) in 1859, led to the gradual growth of a pattern of education similar to that of the rest of the former Indochina Union. Vietnamese attempts to develop education were thwarted by the continued fighting from World War II onward and, after the partition of the country in 1954, by fighting between the South and the North. After the war's end in 1975, the communist government attempted to "reeducate" the conquered South and sought to establish urgently needed technical and vocational education in secondary and higher levels. By the late 1990s there were 10.4 million pupils in elementary schools, 6.6 million in secondary schools, and more than 500,000 in higher-education institutions.

(M.S.H./R.M.T.)

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Egypt

Egypt (Arabic Miṣr), or the Arab Republic of Egypt (Jumhūriyah Miṣr al-'Arabiyah), as it has been known since 1971, has a total area of about 385,230 square miles (997,740 square kilometres). Its land frontiers border Libya in the west, The Sudan in the south, and Israel in the northeast. (Israeli forces occupied the Sinai Peninsula and the Gaza Strip in eastern Egypt after the Arab–Israeli War of 1967. In 1982 the Sinai was returned to Egypt.) In the north its Mediterranean coastline is about 620 miles (1,000 kilometres), and in the east its coastline on the Red Sea and the Gulf of Aqaba is about 1,200 miles. The capital is Cairo.

Egypt was the home of one of the principal civilizations of the ancient Middle East and, like Mesopotamia, of one of the very earliest urban and literate societies. Its culture had an important influence on both ancient Israel and ancient Greece, which in turn helped to form the civilization of the modern West. Egypt also provided Africa with its earliest civilization and may well have had considerable influence on the development of other African cultures.

The special character evident in the civilization of ancient Egypt over a period of 3,000 years developed very rapidly at the time when the country first achieved unity. This great event happened in about 3100 BC, and, while some of the seeds of Egyptian culture had sprouted before this time, it is proper to regard the start of the 1st dynasty as the virtual beginning of Egypt as the country and its civilization are now generally envisaged.

Perhaps the first and most important quality that typified this civilization was continuity. In every aspect of Egyptian life, in every manifestation of its culture, a deep conservatism can be observed. This clinging to the traditions and ways of earlier generations was the particular strength of the Egyptians. It can also be regarded as a weakness; but for a relatively primitive culture there was more to be gained than lost in attachment to the past. Regularity was a built-in characteristic of Egypt; life in the Nile Valley was determined to a great extent by the behaviour of the river itself. The pattern of inundation and falling water, of high Nile and low Nile, established the Egyptian year and controlled the lives of the Egyptian farmers—and most Egyptians were tied to a life on the land—from birth to death, from century to century. On the regular behaviour of the Nile rested the prosperity, the very continuity, of the land. The three seasons of the Egyptian year were even named after the land conditions produced by the river; *akhet,* the "inundation"; *peret,* the season when the land emerged from the flood; and *shomu,* the time when water was short. When the Nile behaved as expected, which most commonly was the case, life went on as normal; when the flood failed or was excessive, disaster followed.

Egypt has always been a hub for routes—westward along the coast of North Africa, northwest to Europe, northeast to the Levant, south along the Nile to Africa, and southeast to the Indian Ocean and the Far East. This natural advantage was enhanced in 1869 by the opening of the Suez Canal, connecting the Mediterranean Sea to the Red Sea. The concern of the European powers to safeguard the Suez Canal for strategic and commercial reasons has probably been the most important single factor influencing the history of Egypt since the 19th century. During the Cold War, for example, the increasing presence of the United States and the Soviet Union in the Mediterranean kept Egypt in the international spotlight. Egypt's traditional significance to the balance of power, however, also lay in its location in Africa and along the Red Sea passage to the Indian Ocean. Both during and after the Cold War, Egypt's central role in the Arabic-speaking world increased its geopolitical importance as Arab nationalism and inter-Arab relations became powerful and emotional political forces in the Middle East and North Africa.

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THE LAND

Relief. The topography of Egypt is dominated by the Nile. For about 750 miles of its northward course through the country, the river cuts its way through bare desert, its narrow valley a sharply delineated strip of green, abundantly fecund in contrast to the desolation that surrounds it. From Lake Nasser, the river's entrance into southern Egypt, to Cairo in the north, the Nile is hemmed into its trenchlike valley by bordering cliffs, but at Cairo these disappear, and the river begins to fan out into its delta. As many as seven branches of the river once flowed through the Delta, but its waters are now concentrated in two, the Damietta Branch to the east and the Rosetta Branch to the west. Though totally flat apart from an occasional mound projecting through the alluvium, the Delta is far from featureless; it is crisscrossed by a maze of canals and drainage channels.

The Nile divides the desert plateau through which it flows into two unequal sections—the Western Desert (Arabic aṣ-Ṣaḥrā' al-Gharbīyah), between the river and the Libyan frontier; and the Eastern Desert (Arabic aṣ-Ṣaḥrā' ash-Sharqīyah), extending to the Suez Canal, the Gulf of Suez, and the Red Sea. Each of them has its own character, as does the third and smallest of the Egyptian deserts, the Sinai. The Western (Libyan) Desert is arid and without wadis (dry beds of seasonal rivers), while the Eastern Desert is extensively dissected by wadis and fringed by rugged mountains in the east. The desert of central Sinai is open country, broken by isolated hills and scored by wadis.

The mountains

Egypt is not, as is often believed, an unrelievedly flat country. Mountainous areas occur in the extreme southwest of the Western Desert, along the Red Sea coast, and in southern Sinai. The high ground in the southwest is associated with the 'Uwaynāt mountain mass, which lies just outside Egyptian territory. A number of peaks in the Red Sea Hills (Ītbāy) rise to more than 6,000 feet (1,800 metres), and the highest, Mount Shāiyb al-Banāt, reaches 7,175 feet (2,187 metres). The sharply serrated crests of the mountains of southern Sinai reach elevations of more than 8,000 feet; among them is Mount Catherine (Jabal Kātrīnā), Egypt's highest mountain, which has an elevation of 8,668 feet (2,642 metres).

The coastal regions of Egypt, with the exception of the Delta, are everywhere hemmed in either by desert or by mountain; they are arid or of very limited fertility. The coastal plain, in both the north and east, tends to be narrow; it seldom exceeds a width of 30 miles. With the exception of the cities of Alexandria, Port Said, and Suez and a few small ports and resorts, the coastal regions are sparsely populated and underdeveloped.

Drainage and soils. Apart from the Nile, the only natural perennial surface drainage consists of a few small streams in the mountains of southern Sinai. Most of the valleys of the Eastern Desert drain westward to the Nile. They are eroded by water but normally dry; only after heavy rainstorms in the Red Sea Hills do they carry torrents. The shorter valleys on the eastern flank of the Red Sea Hills drain toward the Red Sea; they, too, are normally dry. Drainage in the Sinai mountains is toward the gulfs of Suez and Aqaba; as in the Red Sea Hills, torrent action has produced valleys that are deeply eroded and normally dry.

The central plateau of Sinai drains northward toward Wadi al-'Arīsh, a depression in the desert that occasionally carries surface water. One of the features of the Western Desert is its aridity, as shown by the absence of drainage lines. There is, however, an extensive water table beneath the Western Desert. Where the water table comes near the surface it has been tapped by wells in some oases.

Outside the areas of Nile silt deposits, the nature of such cultivable soil as exists depends upon the availability of the water supply and the type of rock in the area. Almost one-third of the total land surface of Egypt consists of Nubian sandstone, which extends over the southern sections of both the Eastern and Western deserts. Limestone deposits of the Eocene Epoch (from 38,000,000 to 54,000,000 years old) cover a further one-fifth of the land surface, including central Sinai and the central portions of both the Eastern and Western deserts. The northern part of the Western Desert consists of Miocene limestone (from 7,000,000 to 26,000,000 years old). About one-eighth of the total area, notably the mountains of Sinai, the Red Sea, and the southwest part of the Western Desert, consists of ancient igneous and metamorphic rocks.

The Nile silt

The silt, which constitutes the present-day cultivated land in the Delta and the Nile Valley, has been carried down from the Ethiopian Highlands by the Nile's upper tributary system, consisting of the Blue Nile and the 'Aṭbarah rivers. The depth of the deposits ranges from more than 30 feet in the northern Delta to about 22 feet at Aswān. The White Nile, which is joined by the Blue Nile at Khartoum, in The Sudan, supplies important chemical constituents. The composition of the soil varies and is generally more sandy toward the edges of the cultivated area. A high clay content makes it difficult to work, and a concentration of sodium carbonate sometimes produces infertile black-alkali soils. In the north of the Delta, salinization has produced the sterile soils of the so-called *barārī* ("barren") regions.

Climate. Egypt lies within the North African desert belt; its general climatic characteristics, therefore, are low annual rainfall and a considerable seasonal and diurnal (daily) temperature range, with sunshine occurring throughout the year. In the desert, cyclones stir up sand or dust storms, called khamsins, which occur most frequently from March to June; these are caused by tropical air from the south that moves northward as a result of the extension northeastward of the low-pressure system of The Sudan. A khamsin is accompanied by a sharp increase in temperature of from 14° to 20° F (8° to 11° C), a drop in relative humidity (often to 10 percent), and thick dust; it can reach gale force.

The climate is basically biseasonal, with winter lasting from November to March and summer from May to September, with short transitional periods intervening. The winters are cool and mild, and the summers are hot. Mean January minimum and maximum temperatures show a variation of between 48° and 65° F (9° and 18° C) in Alexandria and 48° and 74° F (9° and 23° C) at Aswān. The summer months are hot throughout the country, with mean midday June maximum temperatures ranging from 91° F (33° C) at Cairo to 106° F (41° C) at Aswān. Egypt enjoys a very sunny climate, with some 12 hours of sunshine per day in the summer months and between eight and 10 hours per day in winter. Extremes of temperature can occur, and prolonged winter cold spells or summer heat waves are not uncommon.

Humidity diminishes noticeably from north to south and on the desert fringes. Along the Mediterranean coast the humidity is high throughout the year, but it is highest in summer. When high humidity levels coincide with high temperatures, oppressive conditions result.

The rainfall in Egypt occurs largely in the winter months; it is meagre on average but highly variable. The amount diminishes sharply southward; the annual average at Alexandria is about seven inches (178 millimetres), Cairo

has about one inch, and Aswān receives only about one-tenth of an inch. The Red Sea coastal plain and the Western Desert are almost rainless. The Sinai Peninsula receives somewhat more rainfall: the northern sector has an annual average of about five inches.

Plant and animal life. In spite of the lack of rainfall, the natural vegetation of Egypt is varied. Much of the Western Desert is totally devoid of plant life of any kind, but where some form of water exists the usual desert growth of perennials and grasses is found; the coastal strip has a rich plant life in spring. The Eastern Desert receives sparse rainfall; it supports a varied vegetation that includes tamarisk, acacia, and *markh* (a leafless, thornless tree with bare branches and slender twigs), as well as a great variety of thorny shrubs, small succulents, and aromatic herbs. This growth is even more striking in the wadis of the Red Sea Hills and of Sinai and in the Elba Mountains in the southeast.

Water plants

The Nile and irrigation canals and ditches support many varieties of water plants; the lotus of antiquity is to be found in drainage channels in the Delta. There are more than 100 kinds of grasses, among them bamboo and *halfā'* (a coarse, long grass growing near water). Robust perennial reeds such as the Spanish reed and the common reed are widely distributed in Lower Egypt, but the papyrus, cultivated in antiquity, is now found only in botanical gardens.



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The date palm, both cultivated and subspontaneous, is found throughout the Delta, in the Nile Valley, and in the oases. The doum palm (an African fan palm) is identified particularly with Upper Egypt and the oases, although there are scattered examples elsewhere.

There are very few native trees. The Phoenician juniper is the only native conifer, although there are several cultivated conifer species. The acacia is widely distributed, as are eucalyptus and sycamore. The casuarina, one of the most important timber trees in the country, was introduced in the 19th century. Other foreign importations, such as jacaranda, poinciana (a tree with orange or scarlet flowers), and lebbek (a leguminous tree), have become a characteristic feature of the Egyptian landscape.

Domestic animals include buffalo, camels, donkeys, sheep, and goats, the last of which are particularly noticeable in the Egyptian countryside. The animals that figure so prominently on the ancient Egyptian friezes—hippopotamuses, giraffes, and ostriches—no longer exist in Egypt; crocodiles are found only south of the Aswān High Dam. The largest wild animal is the mountain sheep, which survives in the southern fastnesses of the Western Desert. Other desert animals are the dorcas gazelle, the miniature desert fox, the mountain goat, the Egyptian hare, and two kinds of jerboa (a mouselike rodent with long hindlegs for jumping). The Egyptian jackal still exists, and the cony (a small rodent) is found in the Sinai mountains. There are two carnivorous mammals: a species of wildcat and the striped Egyptian mongoose. Several varieties of lizard are found, including the large monitor. Poisonous snakes include more than one species of viper; the speckled snake is found throughout the Nile Valley and the Egyptian cobra in agricultural areas. Scorpions are common in desert regions. There are numerous species of rodents, among which can be found the powerfully built Pharaoh's rat. Many varieties of insects are to be found, including the Egyptian locust.

Bird life

Egypt is rich in bird life. Many birds pass through in large numbers on their spring and autumn migrations; in all, there are more than 200 migrating types to be seen, as well as more than 150 resident birds. The hooded crow is a familiar resident, and the black kite is a characteristic resident along the Nile Valley and in al-Fayyūm. Among the birds of prey are the lanner falcon and the kestrel. Lammergeier and golden eagles are residents of the Eastern Desert and Sinai. The sacred ibis (a long-billed wading bird) is no longer found, but the great egret and buff-backed heron are residents of the Nile Valley and al-Fayyūm, as is the hoopoe (a bird with an erectile, fanlike crest). Resident desert birds are a distinct category, numbering about 24 kinds.

The Nile contains about 190 varieties of fish, the most common being *bulṭī* (a coarse-scaled, spiny-finned fish) and the Nile perch. The lakes on the Delta coast contain mainly *būrī* (gray mullet). Lake Qārūn in al-Fayyūm *muḥāfaẓah* (governorate) has been stocked with *būrī*, and Lake Nasser with *bulṭī*, which grow very large in its waters.

Settlement patterns. Physiographically, Egypt is usually divided into four major regions—the Nile Valley and Delta, the Eastern Desert, the Western Desert, and Sinai. When both physical and cultural characteristics are considered together, however, the country may be divided into six subregions—the Nile Delta; the Nile Valley from Cairo to south of Aswān; the Nubian Valley (since the early 1970s filled by Lake Nasser); the Eastern Desert and the Red Sea coast; Sinai; and the Western Desert and its oases.

The Delta. The Nile Delta, or Lower Egypt, covers an area of 9,650 square miles. It is 100 miles long from Cairo to the Mediterranean, with a coastline stretching 150 miles from Alexandria to Port Said. Much of the Delta coast is taken up by the brackish lagoons of Lakes Maryūṭ, Idkū, Burullus, and Manzilah. The conversion of the Delta to perennial irrigation has made possible the raising of two or three crops a year, instead of one, over more than half of its total area.

The Delta population

About half of the population of the Delta are peasants (fellahin)—either small landowners or labourers—living on the produce of the land. The remainder live in towns or cities, the largest of which is Cairo. As a whole, they have had greater contact with the outside world, particularly with the rest of the Middle East and Europe, than the inhabitants of the more remote southern valley and are generally less traditional and conservative.

The Valley. The cultivated portion of the Nile Valley between Cairo and Aswān varies from five to 10 miles in width, although there are places where it narrows to a few hundred yards and others where it broadens to 14 miles. Since the completion of the Aswān High Dam in 1970, the 2,500,000-acre valley has been under perennial irrigation. The inhabitants of the Valley from Cairo up to Aswān *muḥāfaẓah* are referred to as Ṣa'īdī (Upper Egyptians) and are more conservative than the Delta people. In some areas women still do not appear in public without a veil; family honour is very important, and vendetta laws apply. Until the building of the High Dam, the Aswān *muḥāfaẓah* was one of the poorest in the Valley and the most remote from outside influences.

The Nubian Valley, or Lake Nasser. Until it was flooded by the waters impounded behind the High Dam to form Lake Nasser, the Nubian Valley of the Nile extended for 160 miles between the town of Aswān and the Sudanese border—a narrow and picturesque gorge with a limited cultivable area. The 100,000 inhabitants were resettled, mainly in the government-built villages of New Nubia, at Kawm Umbū (Kom Ombo), north of Aswān. Lake Nasser was developed during the 1970s for its fishing and as a tourist area, and settlements have grown up around it.

The Eastern Desert. The Eastern Desert comprises almost one-fourth of the land surface of Egypt and covers an area of about 85,690 square miles. The northern tier is a limestone plateau, consisting of rolling hills, stretching from the Mediterranean coastal plain to a point roughly opposite Qinā on the Nile. Near Qinā, the plateau breaks up into cliffs about 1,600 feet high and is deeply scored by wadis, which make the terrain very difficult to traverse. The outlets of some of the main wadis form deep bays, which contain small settlements of seminomads. The second tier includes the sandstone plateau from Qinā southward. The plateau is also deeply indented by ravines, but they are relatively free from obstacles, and some are usable as routes. The third tier consists of the Red Sea Hills and the Red Sea coastal plain. The hills run from near Suez to the Sudanese border; they are not a continuous range but consist of a series of interlocking systems more or less in alignment. They are geologically complex, with ancient igneous and metamorphic rocks. These include granite that, in the neighbourhood of Aswān, extends across the Nile Valley to form the First Cataract—that is, the first set of rapids on the river. At the foot of the Red Sea Hills the narrow coastal plain widens southward, and parallel to the shore there are almost continuous coral reefs. In popular conception and usage, the Red Sea Littoral can be regarded as a subregion in itself.

Nomads of the Eastern Desert

The majority of the sedentary population of the Eastern Desert live in the few towns and settlements along the coast, the largest being Ra's Gharib. No accurate figures are available for the nomadic population, but they are believed to constitute about 12 percent of the region's total population. They belong to various tribal groups, the most important being—from north to south—the Ḥuwayṭāt, Ma'āzah, 'Ababdah, and Bishārin. There are more true nomads in the Eastern than the Western Desert because of the greater availability of pasture and water. They live either by herding goats, sheep, and camels or by trading—mainly with mining and petroleum camps or with the fishing communities on the coast.

The Western Desert. The Western Desert comprises two-thirds of the land surface of Egypt and covers an area of about 262,800 square miles. From its highest altitude—more than 3,300 feet—on the plateau of al-Jilf al-Kabīr in the southeast, the rocky plateau slopes gradually northeastward to the first of the depressions that are a characteristic feature of the Western Desert—that containing the oases of al-Khārijah and ad-Dākhilah. Farther north are the hollows containing the oases of al-Farāfirah and al-Baḥriyah. Northwestward from the latter the plateau continues to fall toward the Qattara Depression (Munkhafaḍ al-Qaṭṭārah), which is uninhabited. West of the Qattara Depression and near the Libyan border is the largest and most populous oasis, that of Siwa. It has been inhabited for thousands of years and is less influenced by modern development. South of the Qattara Depression, and extending west to the Libyan border, the Western Desert is composed of great ridges of blown sand, interspersed with stony tracts. Beyond the Qattara Depression northward, the edge of the plateau follows the Mediterranean, leaving a narrow coastal plain.

Outside the oases, the habitable areas of the Western Desert, mainly near the coast, are occupied by the Awlād 'Alī tribe. Apart from small groups of camel herders in the south, the population is no longer totally nomadic. Somewhat less than half are seminomadic herdsmen; the remainder are settled and, in addition to maintaining herds of sheep and goats, pursue such activities as fruit growing, fishing, trading, and handicrafts.

The Western Desert supports a much larger population than the Eastern Desert. Maṭrūḥ, an important summer resort on the Mediterranean, is the only urban centre. Other scattered communities are found mainly near railway stations and along the northern cultivated strip.

The oases, though geographically a part of the Western Desert, are ethnically and culturally distinct. The southern oases of al-Khārijah and ad-Dākhilah have been developed to some extent as part of a reclamation project centred on exploiting underground water resources. Other oases are al-Farāfirah, al-Baḥriyah, and Siwa.

Sinai. Sinai comprises a wedge-shaped block of territory with its base along the Mediterranean coast and its apex bounded by the Gulfs of Suez and Aqaba; it covers an area of approximately 23,000 square miles. Its southern portion consists of rugged, sharply serrated mountains. The central area of Sinai consists of two plateaus, at-Tīh and al-'Ajmah, both deeply indented and dipping northward toward Wadi al-'Arish. Toward the Mediterranean, the northward plateau slope is broken by dome-shaped hills; between them and the coast are long, parallel lines of dunes, some of which are more than 300 feet high. The most striking feature of the coast itself is the 60-mile-long salt lagoon, Lake Bardawīl.

The majority of the population are Arabs, many of whom have settled around al-'Arish and in the northern coastal area, although substantial numbers in the central plateau and the Sinai mountains continue to be nomadic or seminomadic. Another concentration of sedentary population is found at al-Qanṭarah, on the east side of the Suez Canal.

Rural settlement. The settled Egyptian countryside, throughout the Delta and the Nile Valley to the High Dam, exhibits great homogeneity, although minor variations occur from north to south.

Villages of the Delta and the Nile Valley

The typical rural settlement is a compact village surrounded by intensively cultivated fields. The villages range in population from 500 to more than 10,000. They are basically similar in physical appearance and design, except for minor local variations in building materials, design, and decoration. The date palm, sycamore, eucalyptus, and casuarina are common features of the landscape. Until comparatively recently, the only source of drinking water was the Nile; in consequence, many of the villages are built along the banks of its canals. Some of the oldest villages are situated on mounds—a relic of the days of basin irrigation and annual flooding.

In the Delta the houses, one or two stories high, are built of mud bricks plastered with mud and straw; in the southern parts of the Valley more stone is used. The houses are joined to one another in a continuous row. In a typical house the windows consist of a few small round or square openings, barely permitting enough air or light to enter. The roofs are flat, built of layers of dried date leaves, with date-palm rafters; they are used to store corn (maize) and cotton stalks, as well as dung cakes used for fuel. Roofs are also a favourite sleeping place on hot summer nights. For grain storage small cone-shaped silos of plastered mud are built on the roof and are then sealed to prevent the ravages of insects and rodents.

The houses of the poorer peasants usually consist of a narrow passageway, a bedroom, and a courtyard; part of the courtyard may be used as an enclosure for farm animals. Furniture is sparse. Ovens are made of plastered mud and are built into the wall of the courtyard or inside the house. In the larger and more prosperous villages, houses are built of burnt bricks reinforced with concrete, are more spacious, and often house members of an extended family. Furniture, running water, bathroom installations, and electricity are additional signs of prosperity.

Typical features of the smaller Egyptian village, in both the Delta and the Valley, are the mosque or the church, the primary school, the decorated pigeon cote, service buildings belonging to the government, and a few shops. Most of the people in the smaller villages are engaged in agriculture. In the larger villages, there may be some professional and semiprofessional inhabitants as well as more artisans, skilled workers, and shopkeepers. Outside the larger settlements, "combined service units"—consisting of modern buildings enclosing the social service unit, village cooperative, health unit, and school—are sometimes found, standing in striking contrast to the mud houses of the village itself.

The rural life-style

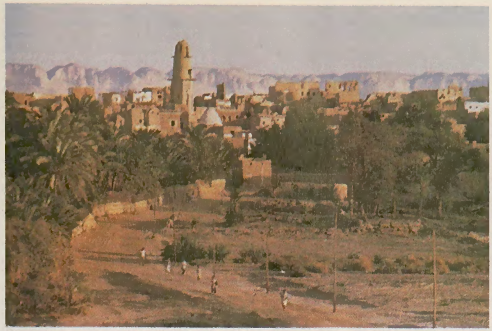
The population density of the inhabited area is such that the presence of people is obvious everywhere, even in the open countryside. In the early morning and the late afternoon, the peasants can be seen in large numbers on the roads, going to or coming from the fields with their farm animals. During the entire day the men, with their long tunics (*gallābiyahs*) tucked up around the waist, can be seen working the land with age-old implements such as the *jās* (hoe) and *minjal* (sickle); occasionally a modern tractor is seen. In the Delta older women in long, black robes, younger ones in more colourful cottons, and children over six years of age help with the less laborious tasks. In some parts of the Valley, however, women over age 16 do not work in the field, and their activities are confined to the household. They seldom appear in public except with a black muslin headdress covering their heads and faces. Young children can be seen everywhere—an omnipresent reminder of the high birthrate.

Unless situated on a highway, villages are reached by unpaved dirt roads. Inside the villages the roads consist mainly of narrow, winding footpaths. All villages, however, have at least one motorable road.

The Western Desert oases are not compact villages but small, dispersed agglomerations surrounded by green patches of cultivation; they are often separated from each other by areas of sand. Al-Khārijah, for example, is the largest of five scattered villages. Traditionally, the houses in the oases were up to six stories high, made of packed mud, and clustered close together for defense. Modern houses are usually two stories high and farther apart.

Urban settlement. Although for census purposes Egyptian towns are considered to be urban centres, some of them are overgrown villages, containing large numbers of peasants and persons engaged in work relating to agriculture and rural enterprises. Some of the towns that have acquired urban status in the second half of the 20th century continue to be largely rural, although they have government officials, people engaged in trade and commerce, industrial workers, technicians, and professional people among their residents. One characteristic of towns and, indeed, of the larger cities is their rural fringe. Towns and cities have grown at the expense of agricultural land, with urban dwellings and apartment buildings mushrooming haphazardly among the fields. There is little evidence of town or city planning or of adherence to building regulations; often mud village houses are embraced within the confines of a city.

Urban characteristics



Al-Qaṣr, in the oasis of ad-Dākhilah in the Western Desert.
© Georg Gerster—Photo Researchers, Inc.

Buildings in towns and smaller cities are usually two-storied houses or apartment blocks four to six stories high. The better ones are lime washed, with flat roofs and numerous balconies; other houses and buildings are often of unpainted red brick and concrete.

Whereas most of the cities of Egypt do not have many distinctive features, some such as Cairo, Alexandria, and Aswān have special characteristics of their own. Cairo is a complex and crowded metropolis, with architecture representing more than 1,000 years of history. Greater Cairo (including al-Jīzah and other suburban settlements) and Alexandria, together with the most important towns along the Suez Canal—Port Said, Ismailia, and Suez—are modern and Western in appearance. Extensive rebuilding of the towns in the canal zone, severely damaged in the fighting between 1967 and 1973, followed the peace treaty with Israel in 1979, and Cairo, badly shaken by an earthquake in 1992, required extensive reconstruction.

THE PEOPLE

The use of Arabic

Linguistic composition. For almost 13 centuries Arabic has been the written and, in its vernacular forms, the spoken language of Egypt. Before the Arab invasion in AD 639, Coptic, the language descended from ancient Egyptian, was the language of both religious and everyday life for the mass of the population; by the 12th century, however, it had been totally replaced by Arabic, continuing only as a liturgical language for the Coptic Orthodox Church. Arabic has become the language of both Christian and Muslim Egyptians.

The written form of the Arabic language has remained substantially unchanged in grammar and syntax since the 7th century. In other ways, however, the written language has changed—the modern forms of style, word sequence, and phraseology are simpler and more flexible than in classical Arabic and are often directly derivative of English or French.

This modern literary Arabic, which is developing out of classical or medieval Arabic, is the lingua franca shared by educated persons throughout the Arab world. Alongside it there exist the various vernacular dialects of Arabic, which differ widely from it as well as from one another. Within the amorphous grouping referred to as Egyptian colloquial, a number of separate dialects can be discerned—each fairly homogeneous but with further strata of variation within the group. One of these is the dialect of the Bedouin of the Eastern Desert and of Sinai; the Bedouin of the Western Desert constitute a separate dialect group. Upper Egypt has its own vernacular, markedly different from that of Cairo. The Cairo dialect is used, with variations, throughout the towns of the Delta; the rural people have their own vernacular. Direct contact with foreigners over a long period has led to the incorporation of many loanwords into Cairene colloquial Arabic. The long contact with foreigners and the existence of foreign-language schools also explains the polyglot character of Egyptian society. Most educated Egyptians are conversant in English or French or both, in addition to both standard and colloquial Arabic.

Non-Arabic languages

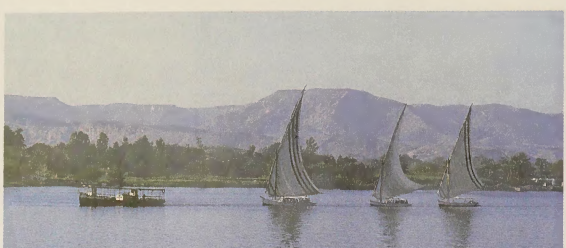
There are other minor linguistic groups. The Beja of the southern section of the Eastern Desert use To Badawī, an Afro-Asiatic language. At Siwa Oasis in the Western Desert there are groups whose language is related to Berber. Nubians speak a language containing both Sudanic and Afro-Asiatic features. There are other minority linguistic groups, notably Greek, Italian, and Armenian, although they are much smaller than they once were.

Ethnic composition. The population of the Nile Valley and the Delta (comprising about 99 percent of Egypt's people) forms a fairly homogeneous ethnic group resulting from the admixture of the indigenous pre-Islāmic population with Arab immigrants. The peasant, or fellah (Arabic: *fallāḥ*), is less ethnically mixed than the town dweller. In the towns—the northern Delta towns especially—the foreign invader, Persian, Roman, Greek, crusader, and Turk, has left behind a more heterogeneous cultural and linguistic mix. The inhabitants of the middle Nile Valley up to Aswān, the Ṣaʿīdī (Upper Egyptians), are of the same ethnic makeup as the inhabitants of the Delta. Settled communities in Aswān *muḥāfaẓah* tend to be a mixture of Ṣaʿīdī, long-settled nomads such as the Jaʿāfirah and ʿAbābdah, and Nubians.

Nubians, though having Arab ancestry, have preserved cultural characteristics that are non-Arab. They differ in that their kinship structure goes beyond the lineage; they are divided into clans and broader segments, whereas among other Egyptians of the Valley and Lower Egypt known members of the lineage are the only ones recognized as kin.

The deserts of Egypt contain nomadic, seminomadic, or sedentary but formerly nomadic groups, with distinct ethnic characteristics. Apart from a few tribal groups of non-Arab ancestry and the mixed urban population, the inhabitants of Sinai and the northern section of the Eastern Desert are all fairly recent immigrants from Arabia. Like the Arabian Bedouin, they form closed, tight-knit communities in which blood relationships are of great importance. Their social organization is tribal, each group conceiving of itself as being united by a bond of blood and as having descended from a common ancestor. Originally tent dwellers and nomadic herders, many have become seminomads or even totally sedentary, as in northern Sinai.

The southern section of the Eastern Desert is inhabited by the Beja. Though claiming Arab descent, they are of different ethnic origin, many living beyond Egypt's bor-



Feluccas on the Nile River, near Luxor in Upper Egypt.
© Robert Frerck—Odyssey Productions

ders in The Sudan and Eritrea where they speak Tigré (a Semitic language) in addition to To Badawī and Arabic. The Egyptian Beja are divided into two tribes—the 'Abābdah and the Bishārīn. The 'Abābdah occupy the Eastern Desert south of a line between Qinā and al-Ghurdaqah; there are also several groups settled along the Nile between Aswān and Qinā. The Bishārīn live mainly in The Sudan, although some dwell in the Elba Mountain region, their traditional place of origin. Both the 'Abābdah and Bishārīn people are nomadic pastoralists who tend herds of camels, goats, and sheep.

The inhabitants of the Western Desert, outside the oases, claim Arab descent but are a mix of Arab and Berber ancestry. They are divided into two groups, the Sa'ādī and the Mūrābiṭīn. The Sa'ādī regard themselves as descended from Banū Hilāl and Banū Sulaymān, the great Arab tribes that immigrated into North Africa in the 11th century. The most important and numerous of the Sa'ādī group are the Awlād 'Alī. The Mūrābiṭīn clans occupy a client status in relation to the Sa'ādī and may be descendants of the original Berber inhabitants of the region. Originally herders and tent dwellers, the Bedouin of the Western Desert have become either seminomadic or totally sedentary. They are not localized by clan, and members of a single group may be widely dispersed.

The Sa'ādī and the Mūrābiṭīn

The original inhabitants of the oases of the Western Desert were of Berber origin. There has, however, been considerable admixture—Egyptian from the Nile Valley, Arab, Sudanese, Turkish, and, particularly in the case of al-Khārijah, sub-Saharan African—for this was the point of entry into Egypt of the caravan route from Darfur, the Darb al-Arba'īn.

In addition to the indigenous groups, there are in Egypt a number of small foreign ethnic groups. In the 19th century there was rapid growth of communities of unassimilated foreigners, mainly European, living in Egypt; these acquired a dominating influence over finance, industry, and government. In the 1920s, which was a peak period, the number of foreigners in Egypt was in excess of 200,000, the largest community being the Greeks, followed by the Italians, British, and French. Since Egypt's independence the size of the foreign communities has been greatly reduced.

Religions. Islām is the official religion of Egypt, and a large majority of the population embrace the Sunnī branch of Islām. A strong sense of piety is a characteristic of the Egyptian Muslim. Prayer is observed punctiliously, particularly public prayer in the mosques, and fasting during the month of Ramaḍān (the ninth month of the Islāmic calendar) is strictly observed. Almsgiving and pilgrimage to Mecca are, if possible, also enjoined.

The Copts

The majority of the Christian population of Egypt are Copts. In language, dress, and way of life they are indistinguishable from Muslim Egyptians; their church ritual and traditions, however, date from before the Arab conquest in the 7th century. Ever since it broke with the Eastern Church in the 5th century, the Coptic Orthodox Church has maintained its autonomy, and its beliefs and ritual have remained basically unchanged. The Copts have traditionally been associated with certain handicrafts and trades and, above all, with accountancy, banking, commerce, and the civil service; there are, however, rural communities that are wholly Coptic, as well as mixed Coptic-Muslim villages.

The Copts are most numerous in the middle Nile Valley *muḥāfaẓāt* of Asyūṭ, al-Minyā, and Qinā in Upper Egypt, which, because of the area's relative geographic isolation, have experienced less intensive Islāmization over the centuries. About one-fourth of the total Coptic population lives in Cairo.

Among other religious groups are the Coptic Catholic, Greek Orthodox, Greek Catholic, Armenian Orthodox and Catholic, Maronite, Syrian Catholic, Anglican, and Protestant. There is also a small Jewish community.

Demographic trends. Most of Egypt's people live along the banks of the Nile River, where the population density, estimated to be more than 2,700 persons per square mile (1,100 persons per square kilometre), is one of the highest in the world. The rapidly growing population is young, with more than one-third of the total under 15 years of age. Despite improvements in health care, infant mortality is high and about half of all deaths occur among children less than five years of age. Life expectancy, however, increased from only about 33 years in 1927 to some 63 years by the early 21st century. Almost half of the population lives in urban areas. (L.S.El H./Ma.J./D.H./C.G.S./Ed.)

THE ECONOMY

The economy of Egypt, according to the constitution of 1971, is one based on socialism, with the people controlling all means of production. The progress of socialism after 1952 was initially hesitant, despite land-reform measures, but it gathered momentum after 1961, when major nationalization steps were taken in an attempt to curb the private sector and destroy the political power of Egyptian capitalists. Until the early 1970s almost all important sectors of the economy either were public or were strictly controlled by the government. This included large-scale industry, communications, banking and finance, the cotton trade, foreign trade as a whole, and many other sectors. Private enterprise came gradually to find its scope restricted, but some room for maneuver was still left in real estate and in agriculture and, later, in the export trade. Personal income, as well as land ownership, was strictly limited by the government. Some of these restrictions have been relaxed, permitting greater private sector participation in various economic areas.

The public sector and the role of government. As the role of the private sector lessened in the 1950s and '60s, that of the government continuously expanded. The government, when not actually in possession, regulates all important aspects of production and distribution. It im-

poses controls on agricultural prices, controls rent, runs the internal trade, regulates foreign travel and the use of foreign exchange, and appoints and supervises the boards of directors of corporations. The government initiates projects and allocates investment. Although the everyday running of corporations is left to the boards of directors, these receive instructions from public boards, and the chairmen of boards receive their instructions from the appropriate minister. The government formulates five-year development plans to guide economic development.

Direct taxation

Taxation. With the majority of the population earning very low incomes, direct taxation falls on the few rich; income-tax rates are made sharply progressive in an attempt to achieve a degree of equality in income distribution. Direct taxes on income, mostly levied on businesses, account for about two-thirds of governmental revenue.

Trade unions and employer associations. Trade unions are closely controlled by the government. Workers obtain a share of the profits earned by corporations and elect their representatives to boards of directors; they are also heavily represented in the National Assembly. In all these activities, however, official selection works side by side with free elections. Trade unions are often vocally active in national policies but are seldom the instrument for negotiating higher wages or better work conditions. There are a few employers' associations, but they have little industrial power.

Contemporary economic policies. In the early 1970s the Egyptian government campaigned for increased foreign investment and began receiving financial aid from the oil-rich Arab states. Although Arab aid was suspended after the signing of the 1979 peace treaty with Israel, the subsequent return of several Western and Japanese corporations, associated with the normalization of Egyptian relations with Israel, increased the potential for further foreign investment in the country. Much of the effort exerted by the government in the early 1980s was devoted to adjusting the economy to the situation resulting from the 1979 Egyptian-Israeli peace treaty. With decreased expenditure on defense, increased allocations were made available for development. Egypt's economy began to be more resilient, primarily because of discoveries of oil and increased Western aid.

Increases in population have put pressure on resources, however, and underemployment has become endemic.

Living standards

Wages and cost of living. The general standard of living in Egypt is rather low; in relation to the size of its population, its economic resources are limited. Land remains its main source of natural wealth, but the amount of land is insufficient to support the population adequately. The realization of the need to curb the rate of population increase led, in 1964, to a national family planning program, which has had only limited success.

The rural population, especially the landless agricultural labourers, has the lowest standard of living in the country. Industrial and urban workers enjoy, on the whole, a higher standard. The highest wages are earned in such industries as the petroleum and manufacturing industries; many workers in industry receive additional benefits by way of social insurance and extra health and housing facilities. The salaries of professional groups are also low. Low wage levels have to some extent been offset by the low cost of living, but by the late 1970s this advantage was eliminated by high inflation rates.

Resources. About 96 percent of Egypt's total area is desert. Lack of forests, permanent meadows, or pastures places a heavy burden on the available arable land, which constitutes only about 3 percent of the total area. This limited area, which sustains on the average almost seven persons per acre, is, however, highly fertile and is cropped more than once a year. Although a large percentage of the population derives its livelihood from agriculture, a growing proportion of the labour force is engaged in manufacturing, and the contribution of the manufacturing and mining sectors to the domestic product has grown to twice that of agriculture—with service activities contributing most of the remainder. Because of the shortage of land, underemployment of labour began to be manifest in agriculture early in the 20th century, and the development of nonagricultural production since then has failed to provide full employment to the increasing labour force.

Mineral resources. Compared with the physical size of the country and the level of its population, the mineral resources of Egypt are scanty. The search for petroleum began earlier in Egypt than elsewhere in the Middle East, and production on a small scale began as early as 1908, but it was not until the mid-1970s that significant results were achieved. By the early 1980s Egypt had become an important oil producer, although total production was relatively small by Middle Eastern standards. Several of Egypt's major known phosphate deposits are mined at Isnā, Ḥamrāwayn, and Safājah. Coal deposits are located in the partially developed Maghara mines in the Sinai Peninsula. Manganese deposits located in the Eastern Desert have been the primary source for manganese production since 1967, and there are also reserves of manganese on the Sinai Peninsula. Egypt mines iron ore from deposits at Aswān, and development work has continued at al-Wāḥāt al-Baḥriyah Oasis. Chromium, uranium, and gold deposits are also found in the country.

Biological resources. Egypt's biological resources, centred around the Nile, have long been one of its principal assets. There are no forests or any permanent vegetation of economic significance, apart from the land under cultivation. Water buffalo, cattle, asses, goats, sheep, and camels are the most important livestock. Animal husbandry and poultry production have continued to increase.

Hydroelectric and other power resources. The Nile constitutes an incomparable source of energy; further sources are represented by coal, oil, and gas deposits. Almost half of Egypt's electrical energy comes from thermal stations; hydroelectric plants, including those at the Aswān High Dam, supply the remainder.

Agriculture and fishing. Agriculture is an important sector of the Egyptian economy. It contributes substantially to the gross national product, employs a large part of the labour force, and provides the country—through agricultural exports—with an important part of its foreign exchange. Increased pressure of population has led to an intensification of cultivation almost without parallel elsewhere. Heavy capital is invested in the form of canals, drains, dams, water pumps, and barrages; the investment of skilled labour, commercial fertilizers, and pesticides is also great. Thus, despite multiple cropping, the yields of the land are exceptionally high. Strict crop rotation—in addition to government controls on the allocation of area to crops, on varieties planted, on the distribution of fertilizers and pesticides, and on marketing—contributes to the high productivity of agriculture.

Investments in agriculture

Unlike the situation in comparable developing countries, Egyptian agriculture has an overwhelmingly commercial rather than subsistence basis. Field crops contribute some three-fourths of the total value of Egypt's agricultural production, while the rest comes from livestock products, fruits and vegetables, and other specialty crops. Egypt has two seasons of cultivation, one for winter and another for summer crops. The main summer field crop is cotton, which occupies more than one-fifth of the season's arable land, absorbs much of the available labour, and represents a sizable portion of the value of exports. Egypt is the world's principal producer of long-staple cotton ($1^1/_8$ inches [2.85 centimetres] and longer), normally producing about one-third of the world crop, although total Egyptian production is only about 3 percent of all cotton produced in the world.

Among other principal field crops are corn (maize), rice, wheat, millet, and broad beans. Despite a considerable output, the cereal production in Egypt falls short of the country's total consumption; a substantial proportion of foreign exchange is spent annually on the import of cereals and milling products. Other important crops include sugarcane, alfalfa (lucerne), potatoes, and onions—the latter being normally an export item. Many varieties of fruit are grown, and some, such as citrus, are also exported.

Reclaimed land

In 1960–61 and 1968–69 about 896,100 acres were reclaimed. The total land reclaimed as a result of the Aswān High Dam project reached more than 1,000,000 acres by 1975, in addition to 700,000 acres converted from basin

(one crop a year) irrigation to perennial irrigation. During the same period, however, an area almost as large was lost to agriculture as industry and towns grew.

Egypt has been the scene of one of the most successful attempts at land reform. In 1952 a limit of 200 acres was imposed on individual ownership of land, and this was lowered to 100 acres in 1961 and to 50 acres in 1969. By 1975 less than one-eighth of the total cultivated area was held by owners with 50 acres or more. The success of Egyptian land reform is indicated by the substantial rise of land yields after 1952. This was partly the result of several complementary measures of agrarian reform, such as regulation of land tenure and rent control, that accompanied the redistribution of the land.

Following the construction of the Aswān High Dam, the Egyptian government encouraged the development of a thriving fishing industry. Construction of such projects as a fish farm and fishery complex at Lake Nasser have led to a considerable increase in the number of freshwater fish and in the size of the yearly total catch. At the same time, catches of sea fish in the waters off the Nile Delta have declined. This is thought to be a consequence of the change in the flow and character of Nile water after the construction of the Aswān High Dam.

Industry. The development of the manufacturing industry was handicapped by the policy of free trade imposed on Egypt from the middle of the 19th century until about 1930. Nationalism and World War II gave great impetus to the foundation of industrial projects that are largely agriculturally based and oriented toward import substitution. During the 1950s the country's manufacturing sector began to grow, and manufacturing and mining now account for a substantial portion of the gross domestic product.

Emphasis was placed on the development of heavy industry after a long-term agreement was signed with the Soviet Union in 1964. Another agreement with the Soviet Union, signed in 1970, provided aid for the expansion of the iron and steel complex at Ḥulwān; the establishment of a number of power-based industries, including an aluminum complex to utilize the power generated by the High Dam; and the electrification of the countryside. An ammonium nitrate fertilizer plant was opened in 1971, based on the gases generated in the coking unit of the steel mill at Ḥulwān. There is also a nitrate fertilizer plant at Aswān.

Egypt has made great achievements in increasing industrial production in such traditional industries as spinning and weaving, as well as in modern industries like engineering and iron and steel production. Food processing and the manufacture of chemical products also are important to the Egyptian economy.

Energy

Before the completion of the Aswān High Dam power station in 1970, the bulk of Egypt's electricity was generated in thermal stations using coal or diesel fuel, but some hydroelectric power was also generated by the old Aswān Dam. The 12 turbines of the High Dam power station have a capacity of about 2,000,000 kilowatts and are capable of producing 10,000,000,000 kilowatt-hours a year; the capacity of the thermal stations is about 45 percent of that of the High Dam. Transmission lines carry the current from Aswān to Cairo and to points farther north for use in urban centres and in manufacturing. The production of electric power from the High Dam has been limited, however, by the need to reconcile demands for power with the demands for irrigation water.

The bulk of Egypt's petroleum comes from the rich Morgan, Ramadan, and July fields (both onshore and offshore) in the Gulf of Suez, which are operated by the Gulf of Suez Petroleum Company, and from the Abū Rudays area of the Sinai on the Gulf of Suez. In cooperation with Phillips Petroleum Company, Egypt also extracts oil from fields at al-'Alamayn and Razzāq in the Western Desert. Active drilling for oil, involving several international interests, including those of the United States and several European nations, has continued in both the Eastern and the Western deserts.

Natural gas

In the process of searching for oil, some significant natural gas deposits have been located. Phillips has located wells in the Abū Qir area, northeast of Alexandria. A joint Egyptian-Italian gas discovery was made in the north Delta near Abū Māḍī in 1970; this was developed partly to supply a fertilizer plant and partly to fuel the industrial centres in the north and northwest Delta. In 1974 Abū Māḍī became the first Egyptian gas field to begin production. Other natural gas fields are located in the Western Desert and the Gulf of Suez.

Egypt has several oil refineries, two of which are located at Suez. The first of Egypt's twin crude pipelines, linking the Gulf of Suez to the Mediterranean near Alexandria, was opened in 1977. This Suez–Mediterranean pipeline, known as Sumed, has an annual capacity for transmitting 80,000,000 tons of oil. The Sumed pipeline was financed by a consortium of Arab countries, primarily Saudi Arabia, Kuwait, and Egypt. In 1981 a crude oil pipeline was opened to link Ras Shuqir, on the Red Sea coast, with the refinery at Musturud, north of Cairo. An additional oil pipeline links Musturud with Alexandria.

Finance. The banking system of Egypt is centred on the Central Bank of Egypt, created in 1960 from the issue department of the National Bank of Egypt. In 1961 all banks operating in Egypt were nationalized, and their operations were concentrated in five commercial banks, in addition to the Central Bank, the government-sponsored Public Organization for Agricultural Credits and Co-operatives, the Development Industrial Bank, and three mortgage banks.

The government again reorganized the banking system in the early 1970s, merging some of the major banks and assigning special functions to each of the rest. Two new banks were created, and foreign banks were again permitted in the country as part of a program aimed at liberalizing the economy. Of particular interest were joint banking ventures between Egyptian and foreign banks. The stock exchanges at Cairo and Alexandria, which had been closed since the early 1960s, were reopened. The cotton exchanges in Cairo and Alexandria, which had also been closed, were replaced by a supervisory council responsible for regulating the cotton industry. In 1980 Egypt's first international bank was opened and a national investment bank was established.

The supply of money has, in general, followed the development of the economy; the authorities have aimed at tolerable increases in the price level, although since the 1973 war some prices have soared and inflation rates have risen sharply.

Egypt is a member of the International Monetary Fund (IMF). Since World War II the international liquidity of the Egyptian economy, including the Special Drawing Rights, added in 1970, has been depressed. In the late 1970s both internal and external debts rose, primarily because of large government subsidies to the private sector. In the 1980s the government gradually introduced price increases on goods and services, with the goal of eventually reducing subsidies.

Imports and exports

Trade. Imports into Egypt average about one-third and exports about one-tenth of the gross domestic product. Since World War II exports have tended to fall short of imports. The trade deficit reached a peak in 1966 and was particularly sizable from 1960 to 1965 as expenditure on development rose. After the 1973 war there was a decided effort to restrict imports and stimulate exports, but this met with little success. The trade deficit continued to rise to record highs in the early and mid-1980s, largely because of the decline in revenue from petroleum exports and the increase in food imports.

Almost two-thirds of imports consist of raw materials, mineral and chemical products, and capital goods (machinery, electrical apparatus, and transport equipment), more than one-fourth are foodstuffs, and the remainder are other consumer goods. More than one-half of the exports by value consist of petroleum and petroleum products, followed by raw cotton, cotton yarn, and fabrics. Raw materials, mineral and chemical products, and capital goods are also exported. Among agricultural exports are rice, onions, garlic, and citrus fruit.

Italy and France are among Egypt's largest markets. The United States, however, is the major source of Egypt's imports, followed by Germany, Italy, and France.

The economic boycott by other Arab states, which resulted from the 1979 peace treaty between Israel and Egypt, did not have a serious effect on Egypt's economy. In the early and mid-1980s Egypt's revenue fluctuated, however, in response to changes in oil sales and tourist revenue, and the country continued to have deficits in its foreign-trade balance. The deficit has been financed by international borrowing (primarily from the International Monetary Fund), transfers from Arab oil-producing countries, revenue from expatriate remittances, Suez Canal revenue, and changes in foreign assets and liabilities.

(E.I.U./D.H./C.G.S.)

Transportation. Almost the entire communications system is state-owned. It is adequate in terms of coverage, but stresses arise from excessive usage. The main patterns of transport flow reflect the topographical configuration of the country—that is to say, they follow the north–south course of the Nile, run along the narrow coastal plain of the Mediterranean Sea, and expand into a more complex system in the Delta.

Road network. About half of Egypt's total road network is paved. Rural roads are of dried mud, usually following the lines of the irrigation canals; many of the desert roads are little more than tracks. The Cairo–Alexandria highway runs via Banhā, Ṭanṭā, and Damanhūr. The alternate desert road to Cairo from Alexandria has been extensively improved, and a good road links Alexandria with Libya by way of Maṭrūḥ on the Mediterranean coast. There are paved roads between Cairo and al-Fayyūm, and good roads connect the various Delta and Suez Canal towns. A paved road parallels the Nile from Cairo south to Aswān, and another paved road runs from Asyūṭ to al-Khārijah and ad-Dākhilah in the Western Desert. The coastal Red Sea route to Marsā al-'Alām is poorly paved, as are the connecting sections inland.

Railways. Railways connect Cairo with Alexandria and with the Delta and canal towns and also run southward to Aswān and the High Dam. Branch lines connect Cairo with al-Fayyūm and Alexandria with Maṭrūḥ. A network of light railways connects the Fayyūm area and the Delta villages with the main lines. Diesel-driven trains operate along the main lines; electric lines connect Cairo with the suburbs of Ḥulwān and Heliopolis.

Rivers and canals

Navigable waterways. The Suez Canal, closed in 1967, was reopened in 1975; it serves as a major link between the Mediterranean and Red seas. The Nile and its associated navigable canals provide an important means of transportation, primarily for heavy goods. There are roughly 2,000 miles of navigable waterways—about one-half of this total on the Nile, which is navigable throughout its length. The inland-waterway freight fleet consists of tugs, motorized barges, towed barges, and flat-bottomed feluccas (two- or three-masted lateen-rigged sailing ships).

Ports and shipping. In spite of its long coastline, Egypt has only three ports of any significance—Alexandria, Port Said, and Suez. Alexandria, with a fine natural harbour, handles most of the country's imports and exports, as well as the bulk of passenger traffic. Port Said, at the northern entrance to the Suez Canal, lacks the berthing and loading facilities of Alexandria. Suez's main function is that of an entry port for petroleum and minerals from the Egyptian Red Sea coast and for goods from the Far East.

Air transport. Cairo is an important communication centre for world air routes. The enlarged airport at Heliopolis, with its modern terminal building, is used by major international airlines, as is Nuzhah airport at Alexandria. The national airline, Egypt Air, runs external services throughout the Middle East, as well as to Europe, North America, Africa, and the Far East; it also operates a domestic air service.

GOVERNMENT AND SOCIAL CONDITIONS

Government. Before the 1952 revolution, Egypt was a constitutional monarchy; the 1923 constitution, which followed the declaration of the end of the British protectorate, stated that Egypt was an independent sovereign Islāmic state with Arabic as its language and provided for a representative parliament. This constitution was abolished in 1952, political parties were dissolved in 1953, and a new constitution was introduced in 1956. The Republic of Egypt was declared. Between 1958 and 1961 Egypt and Syria were merged into one state, called the United Arab Republic; the name was retained by Egypt upon Syria's secession in 1961. The National Union, organized in 1957 in place of the political parties abolished in 1953, became the Arab Socialist Union (ASU) in 1962.

In 1971 Egypt, Libya, and Syria agreed to establish the Confederation of Arab Republics. A draft constitution was accepted by the heads of state of each country and was approved by referenda in each of the three member states. The capital of the confederation was Cairo. In 1979, however, deteriorating relations between Egypt and other Arab nations led to the end of the confederation; following the signing of the Egyptian-Israeli peace treaty, most Arab economic ties with Egypt also were suspended.

On Sept. 11, 1971, a new constitution for Egypt was approved by referendum. It proclaimed the Arab Republic of Egypt to be "a democratic, socialist state" with Islām as its state religion and Arabic as its national language. It recognized three types of ownership—public, cooperative, and private. It guaranteed the equality of all Egyptians before the law and their protection against arbitrary intervention in the processes of law. It also affirmed the rights to peaceful assembly, education, and health and social security and the right to organize into associations or unions and to vote.

According to the constitution and its subsequent amendments, the president of the republic is the head of state and, together with the Cabinet, constitutes the executive authority. The president must be Egyptian, born of Egyptian parents, and not less than 40 years old. The presidential term is six years and may be extended to additional terms. The president has the power to appoint and dismiss one or more vice presidents, the prime minister, ministers, and deputy ministers. The legislative body is composed of the People's Assembly, which nominates the presidential candidate by a two-thirds majority. The candidate is then confirmed by national plebiscite.

The president is the supreme commander of the armed forces and has the right to grant amnesty and reduce sentence, the power to appoint civil and military officials and to dismiss them in a manner prescribed by the law, and the authority to call a referendum on matters of supreme importance. The president can, in exceptional cases and by investiture of the assembly, issue decrees having the force of law—but only for a defined time period.

The People's Assembly

Legislative power resides in the People's Assembly, which is composed of 444 elected members, some of whom must be women, and 10 additional members appointed by the president. The assembly is elected, under a complex system of proportional representation, for a five-year term. All males 18 years of age and older are required to vote, as well as all women on the register of voters. The president convenes and closes the sessions of the People's Assembly.

The People's Assembly's main function is to approve policy. Its members must ratify all laws and examine and approve the national budget. It also approves the program of each newly appointed Cabinet. Should it withdraw its confidence from the Cabinet or any of its members, that person is required to resign. The president cannot dissolve the assembly except under special circumstances and after a vote of approval by a people's referendum. Elections for a new assembly must be held within 60 days of dissolution.

The constitution also provides for a judiciary, independent of other authorities, whose functions and authority are governed by special legislation, and, as a result of an amendment approved by a 1980 referendum, for the Shura Assembly, a partially elective national advisory body. The National Defence Council, presided over by the president of the republic, is responsible for matters relating to security and defense.

Local government and administration. Until 1960, government administration was highly centralized; in that year, however, the local-government administrative system was established to promote decentralization and greater citizen participation in local government.

The 1960 Local Administration Law provides for three levels of local administration—the *muḥāfaẓāt* (gover-

Governorates, districts, and villages

norates), the *markaz* (districts or counties), and the *qarīyah* (villages). The structure combines features of both local administration and local self-government. There are two councils at each administrative level: a mostly elected people's council and an appointed executive council. Although these councils exercise broad legislative powers, they are controlled by the central government.

The country is divided into 26 *muḥāfaẓāt*. Five cities—Cairo, Alexandria, Ismailia, Port Said, and Suez—have *muḥāfaẓah* status. The governor is appointed and can be dismissed by the president of the republic. He is the highest executive authority in the *muḥāfaẓah*, has administrative authority over all government personnel except judges in his *muḥāfaẓah*, and is responsible for implementing policy.

The *muḥāfaẓah* council is composed of a majority of elected members. Although it has not been possible in practice, according to law at least one-half of the members of the *muḥāfaẓah* council are to be farmers and workers. The town or district councils and the village councils are established on the same principles as those underlying the *muḥāfaẓah* councils.

The local councils perform a wide variety of functions in education, health, public utilities, housing, agriculture, and communications; they are also responsible for promoting the cooperative movement and for implementing parts of the national plan. Local councils obtain their funds from national revenue, a tax on buildings and lands within the *muḥāfaẓah*, miscellaneous local taxes or fees, profits from public utilities and commercial enterprises, and national subsidies, grants, and loans.

The political process. After 1962 all popular participation and representation in the political process was through the Arab Socialist Union. In 1976, however, the ASU lost its status as the sole legal political organization, and other political parties soon formed; their right to exist was recognized by a law adopted in June 1977. The ASU was abolished by constitutional amendment in 1980.

The Arab Socialist Union

The National Democratic Party (NDP), formed by Pres. Anwar el-Sādāt in 1978, serves as the official government party and holds a majority of seats in the People's Assembly. The left-wing opposition is the National Progressive Unionist Party and the Socialist Labour Party. The prerevolutionary Wafd Party has been re-formed, and one religious party, the Umma, has been licensed. Officially unrepresented are the Communists, extreme religious groups, and avowed Nasserists.

Justice. The Egyptian constitution emphasizes the independent nature of the judiciary. There is to be no external interference with the due processes of justice. Judges are subject to no authority other than the law; they cannot be dismissed and are disciplined in the manner prescribed by law. Judges are appointed by the state, with the prior approval of the Supreme Judicial Council under the chairmanship of the president. The council is also responsible for the affairs of all judicial bodies; its composition and special functions are specified by law.

The courts

The court structure can be regarded as falling into four categories, each of which has a civil and criminal division. These courts of general jurisdiction include district tribunals, tribunals of the first instance, courts of appeal, and the Court of Cassation. Court sessions are public, except where consideration of matters of public order or decency decides otherwise. Sentence is passed in open session.

In addition, there are special courts, such as military courts and courts of public security—the latter dealing with crimes against the well-being or security of the state. The Council of State is a separate judicial body, dealing especially with administrative disputes and disciplinary actions. The Supreme Constitutional Court in Cairo is the highest court in Egypt. Its functions include judicial review of the constitutionality of laws and regulations and the resolution of judicial conflicts among the courts.

Law enforcement. The Ministry of the Interior has direct control and supervision over all police and security functions at the *muḥāfaẓah*, district, and village levels. At the central level, the deputy minister for public security is responsible for general security, emigration, passports, port security, criminal investigation, ministerial guards, and emergency services. The deputy minister for special police is responsible for civil defense, traffic, prison administration, tourist police, and police transport and communications.

Education. At the end of the 19th century there were only three secondary and nine "higher" schools in Egypt; the educational structure continued to be based on the *kuttābs*, or Qur'ān schools. In 1916 the latter were turned into elementary schools, and in 1923 a law was passed providing free compulsory education between the ages of seven and 12. A sharp increase in the annual budgetary allocation devoted to education occurred after World War II. Following the revolution of 1952, educational progress already achieved was accelerated and was accompanied by both the Egyptianization and Arabicization of the educational system. One of the most significant features of this progress has been the spread of women's education. By the late 1970s almost one-third of the students attending university were women. Women are no longer confined to the home; many fields of employment, including the professions and even politics, are now open to them. A further result of the expansion of education has been the emergence of an intellectual elite and the growth of a middle class, consisting of members of the professions, government officials, and businessmen. In spite of the rapid advance in the provision of education services, however, illiteracy has remained relatively high.

There are three stages of state general education—primary (six years), preparatory (three years), and secondary (three years). Primary education between the ages of six and 12 is compulsory. Pupils who are successful in examinations have the opportunity to continue their education first at the preparatory and then at the secondary level. There are two types of secondary school, general and technical; most technical schools are either commercial, agricultural, or industrial.

Alongside the Ministry of Education's system of general education, there is that provided by the institutes associated with al-Azhar University, centred on al-Azhar Mosque in the medieval quarter of Cairo. Al-Azhar has been a teaching centre for the entire Muslim world for nearly a millennium. Instruction is given at levels equivalent to those of the state schools, but in order to allow for greater emphasis on traditional Islāmic subjects, the duration of training is lengthened by one year at the preparatory stage and two at the secondary. A large-scale modernization of the college-level curriculum, making it comparable to those of other state universities, has been carried out since 1961.

In the 1950s there were almost 300 foreign schools in Egypt, the majority of them French; many of these have since become, to varying degrees, Egyptianized. Pupils who attend these schools, at all levels, sit for the same state certificate examinations as those in the normal state system.

The universities

The major state universities are Cairo, Alexandria, 'Ayn Shams, and Asyūṭ. In addition to the state university system, there is one private university, the American University in Cairo.

There are many institutes of higher learning, excluding institutes attached to universities or affiliated to the Ministry of Culture—such as the Institute of Dramatic Arts, the Cinema Institute, and the Institute of Ballet. These institutes specialize in commerce, industry, agriculture, the arts, physical culture, social service, domestic economy, and languages. Courses of study lead to a degree.

Health and welfare. The budget of the Ministry of Health has reflected a steadily increasing expenditure on public-health programs, and the numbers of government health centres, beds in public hospitals, doctors, and dentists have increased dramatically.

An important aspect of this development has been the expansion of health facilities in the rural areas of the country. In 1953 the government introduced what are termed combined service units; these differ from health centres in that they combine the functions of health centre, school, social-welfare unit, and agricultural extension services. In addition, rural health units further extend the health services available in rural communities. Each unit

is operated by a team of seven or eight people, including one physician.

Well-trained physicians and specialists are available in large numbers in the cities and larger towns. The medical profession has prestige, and only the better qualified high school graduates are accepted into medical schools.

Public health campaigns

Significant efforts have been made to promote preventive medicine. Compulsory vaccination against smallpox, diphtheria, tuberculosis, and poliomyelitis is enforced for all infants during their first two years. Schistosomiasis, a parasitic disease that is widespread among the rural population, presents a serious health problem. All health centres offer treatment against it, but reinfection can easily occur. Epidemics of malaria have been eliminated, but the disease still exists in endemic form, mainly in southern Egypt. Treatment for malaria is provided at all health centres, and the spraying of houses in mosquito-breeding areas is carried out regularly. Attention has also been given to the problem of tuberculosis; centres have been established in every *muḥāfaẓah*, and mass X-ray and immunization campaigns have been carried out.

The government has attempted to socialize medicine through such measures as the nationalization and control of pharmaceutical industries, the nationalization of hospitals run by private organizations and associations, and expanded health insurance. A health insurance law was passed in 1964; it provides for compulsory health insurance for workers in firms employing more than 100 persons, as well as for all governmental and public employees.

Housing. Egypt has faced a serious urban housing shortage since World War II. The situation subsequently became aggravated by increased immigration from rural to urban areas, resulting in extreme urban overcrowding.

Although there is considerable concern over the housing problem, the combined efforts of both public and private sectors have been unable to meet the growing demand.

Housing construction

Between 1970 and 1980, for example, approximately 300,000 housing units were built; this represented an increase of more than one-fourth of the total number of housing units. The increase in the urban population, however, was estimated at more than 40 percent during the same period; *i.e.,* for every new housing unit built, 13 persons were added to the urban population.

In the rural areas villagers build their own houses at little cost with the materials available. The government has experimented in aiding self-help projects with state loans. Ambitious rural housing projects have been carried out on newly reclaimed land: entire villages with all the necessary utilities have been built.

CULTURAL LIFE

In spite of the many ancient civilizations with which it has come into contact, Egypt unquestionably belongs to a sociocultural tradition that is Arabic and Islāmic. This tradition remains a constant factor in determining Egyptian views both of itself and of the world.

The story of the cultural development of modern Egypt is, in essence, that of the response of this traditional system to the intrusion into it, at first by conquest and later by the penetration of ideas, of the alien and materially superior civilization of the West. The response covered a broad spectrum—from the rejection of new ideas and reversion to traditionalism through self-examination and reform to an uncritical acceptance of new concepts and the values that went with them. The result has been the emergence of a cultural identity devoid of self-consciousness, which has assimilated much that is new, while remaining distinctively Egyptian. The process is to be seen at work in all branches of contemporary culture.

The state of the arts. The impact of the West is one of the recurring themes in the modern Egyptian novel, as in Tawfiq al-Ḥakīm's '*Uṣfūr min ash-Sharq* ("The Bird from the East") and Yaḥyā Ḥaqqī's novella *Qindīl Umm Hāshim* ("The Lamp of Umm Hāshim"). A further theme is that of the Egyptian countryside—romantically handled at first, as in Muḥammad Ḥusayn Haykal's *Zaynab,* and later realistically, as in 'Abd al-Raḥmān ash-Sharqāwī's *al-Arḍ* (*The Land*) and *al-Fallāḥ* ("The Peasant") and in Yūsuf Idrīs' *al-Ḥarām* ("The Forbidden"). A Dickensian capacity to catch the colour of life among the urban poor is a characteristic quality of the early and middle work of Egypt's greatest modern novelist, Najīb Maḥfūẓ, notably in *Zuqāq al-Midaqq* (*Midaq Alley*).

The modern theatre in Egypt is a European importation—the first Arabic-speaking plays were performed in 1870. Two dramatists, both born at the turn of the century, have dominated its development—Maḥmūd Taymūr and Tawfīq al-Ḥakīm. The latter, a versatile and cerebral playwright, has reflected in his themes not only the development of the modern theatre but also, in embryo, the cultural and social history of modern Egypt. The changes in Egyptian society are reflected in the themes adopted by younger dramatists.

Film-making in Egypt

There is a relatively long tradition of filmmaking in Egypt going back to World War I, but it was the founding of Miṣr Studios in 1934 that stimulated the growth of the Arabic-speaking cinema. Modern Egyptian films are shown to audiences throughout the Arab world and are also distributed in Asian and African countries. The industry is both privately and state owned—there are many private film-production companies, as well as the Ministry of Culture's Egyptian General Cinema Corporation.

Contemporary Egyptian music embraces indigenous folk music, traditional Arabic music, and Western-style music. The revival of traditional Arabic music, both vocal and instrumental, owes much to state sponsorship. Popular Arabic music consists of a blend of classical Arabic music, folk songs, and Western music. Muḥammad 'Abd al-Wahhāb has been one of the leading figures in the development of this genre, as both composer and singer. Umm Kulthūm was the leading vocalist not only of Egypt but also of the whole Arab world for almost 50 years. Western-style music has been a familiar component in Egyptian musical culture since the 19th century. Pioneers such as Yūsuf Greiss and Abū Bakr Khayrat succeeded in incorporating Arabic elements to give a national colouring to their Western-style compositions.

A return to folklore as a source of inspiration for the arts is a generalized phenomenon in modern Egyptian culture. It has resulted in a revived interest in traditional crafts, in the collection of folk music, and the maintaining, with government sponsorship, of two folk-dance ensembles—the Riḍā Troupe and the National Folk Dance Ensemble. In the plastic arts the highly original use of local themes is particularly striking. An active school of Egyptian painting and sculpture has emerged.

Cultural institutions. The oldest learned academy in Egypt, the Institut d'Égypte, was founded in 1859, but its antecedents go back to the institute established by Napoleon in 1798. The Academy of the Arabic Language, founded in 1932 and presided over by the veteran educator Ṭaha Ḥusayn, became, in terms of prestige and influence, one of the most important cultural institutions in Egypt. Linked to the Ministry of Culture, it enjoys a large measure of autonomy, guaranteed by its own charter. Also attached to the Ministry of Culture is the Higher Council for Arts, Letters, and the Social Sciences. Intended as a consultative body on cultural matters, the Higher Council is also a means of channeling state patronage.

The learned societies

Learned societies in Egypt support a wide variety of interests—including the physical and natural sciences, medicine, agriculture, the humanities, and the social sciences. Increased government concern with research, especially in science and technology, was reflected in the founding of the National Research Centre, where laboratory work in both pure and applied science began in 1956, and of the Atomic Energy Establishment, in 1957. In addition, there are many specialized research institutes in the country.

Most of the learned societies and research institutes have library collections of their own. In addition to large collections at the universities, the municipalities of Alexandria, al-Manṣūrah, and Ṭanṭā maintain libraries. There is also a central public library in each *muḥāfaẓah,* with branches in small towns and service points in the villages. The Ministry of Culture is responsible for the Egyptian National Library (Dār al-Kutub) and the National Archives, both in Cairo, and the Public Libraries Administration. The

Egyptian National Library, which has a large collection of printed materials, is also a centre for the collection and preservation of manuscripts.

The Ministry of Culture is also responsible, through its department of antiquities, for the Egyptian Museum, the Coptic Museum, and the Museum of Islāmic Art, all in Cairo; the Greco-Roman Museum in Alexandria; and for other institutions, including fine-arts museums such as the Mukhtār Museum, the Nāji Museum, and the Museum of Modern Art, all in Cairo, and the Museum of Fine Arts in Alexandria.

All newspapers and magazines in Egypt are subject to supervision through the government's Supreme Press Council. Daily newspapers include the long-established *al-Ahram*, published in Cairo, and other Arabic-language papers, together with daily English-language and French-language newspapers. The government owns and operates the Egyptian Radio and Television Corporation, which provides programs in a variety of languages. Cairo is considered to be the largest centre of publishing in the Middle East.

For statistical data on the land and people of Egypt, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR. (L.S.El H./Ma.J./D.H./C.G.S.)

History

INTRODUCTION TO ANCIENT EGYPTIAN CIVILIZATION

Life in ancient Egypt. Ancient Egypt can be thought of as an oasis in the desert of northeast Africa, dependent on the annual inundation of the Nile to support its agricultural population. The country's chief wealth came from the fertile floodplain of the Nile Valley, where the river flows between bands of limestone hills, and the Nile Delta, in which it fans into several branches north of modern Cairo. Between the floodplain and the hills is a variable band of low desert, which supported a certain amount of game. The Nile was Egypt's sole transportation artery.

The Nile floodplain

The First Cataract at Aswān, where the riverbed is turned into rapids by a belt of granite, was the country's only well-defined boundary within a populated area. To the south lay the far less hospitable area of Nubia, in which the river flowed through low sandstone hills that left a very narrow strip of cultivable land. Nubia was significant for Egypt's periodic southward expansion and for access to products from farther south. West of the Nile was the arid Sahara, broken by a chain of oases some 125–185 miles (about 200–300 kilometres) from the river and lacking in all other resources except for a few minerals. The eastern desert, between the Nile and the Red Sea, was more important, for it supported a small nomadic population and desert game, contained numerous mineral deposits including gold, and was the route to the Red Sea.

To the northeast was the Isthmus of Suez. It offered the principal route for contact with Sinai, from which came turquoise and possibly copper, and with western Asia, Egypt's most important area of cultural interaction, from which were received stimuli for technical development and cultivars for crops. Immigrants and ultimately invaders crossed the Isthmus into Egypt, attracted by the country's stability and prosperity. From the late 2nd millennium BC on, numerous attacks were made by land and sea along the eastern Mediterranean coast.

At first, relatively little cultural contact came by way of the Mediterranean Sea, but from an early date Egypt maintained trading relations with the Lebanese port of Byblos (modern Jubayl). Egypt needed few imports to maintain basic standards of living, but good timber was essential and not available within the country, so it usually was obtained from Lebanon. Minerals such as obsidian and lapis lazuli were imported from as far afield as Anatolia and Afghanistan.

Agriculture

Agriculture centred on the cultivation of cereal crops, chiefly emmer wheat (*triticum dicoccum*) and barley (*hordeum vulgare*). The fertility of the land and general predictability of the inundation ensured very high productivity from a single annual crop. This productivity made it possible to store large surpluses against crop failures and also formed the chief basis of Egyptian wealth, which was, until the creation of the large empires of the 1st millennium BC, the greatest of any state in the ancient Near East.

Irrigation was achieved by simple means and multiple cropping was not feasible until much later times, except perhaps in the lakeside area of Fayyūm. As the river deposited alluvial silt, raising the level of the floodplain, and land was reclaimed from marsh, the area available for cultivation in the Nile Valley and Delta increased, while pastoralism declined slowly. In addition to grain crops, fruit and vegetables were important, the latter being irrigated year-round in small plots; and fish was vital to the diet. Papyrus, which grew abundantly in marshes, was gathered wild and in later times was cultivated. It may have been used as a food crop; and it certainly was used to make rope, matting, and sandals. Above all it provided the characteristic Egyptian writing material, which, with cereals, was the country's chief export in Late Period Egyptian and then Greco-Roman times.

After the introduction of cultivated cereal crops, meat was eaten mainly by the wealthy. Domesticated animals lost much of their significance for nutrition, but they retained great cultural importance and practical value. Cattle may have been domesticated in northeastern Africa. The Egyptians kept many as draft animals and for their various products, showing some of the interest in breeds and individuals that is found to this day in the Sudan and eastern Africa. The donkey, which was the principal transport animal (the camel did not become common until Roman times), was probably domesticated in the region. The native Egyptian breed of sheep became extinct in the 2nd millennium BC and was replaced by an Asiatic breed. Wool was rarely used, so that sheep were primarily a source of meat. Goats were more numerous than sheep and were commonly depicted browsing on tree foliage. Pigs, although subject to some sort of taboo, were raised and eaten. Ducks and geese were kept for food, and many of the vast numbers of wild and migratory birds found in Egypt were hunted and trapped. Desert game, principally various species of antelope and ibex, were hunted by the elite; it was a royal privilege to hunt lions and wild cattle. Pets included dogs, which were also used for hunting; cats (domesticated in Egypt); and monkeys. In addition, the Egyptians had a great interest in, and knowledge of, most species of mammals, birds, reptiles, and fish in their environment.

Most Egyptians were probably descended from settlers who came to the Nile Valley in prehistoric times, with increase coming through natural fertility. In various periods there were immigrants from Nubia, Libya, and especially the Near East. They were historically significant and may have contributed to population increase, but their numbers are unknown. Most people lived in villages and towns in the Nile Valley and Delta. Dwellings were normally built of mud brick and have long since disappeared beneath the rising water table, thereby obliterating evidence for settlement patterns. In antiquity, as now, the most favoured location of settlements was on slightly raised ground near the riverbank, where transport and water were easily available and flooding was unlikely. Until the 1st millennium BC Egypt was not urbanized to the same extent as Mesopotamia. Instead, a few centres, notably Memphis and Thebes, attracted population and particularly the elite, while the rest of the people were relatively evenly spread over the land. The size of the population has been estimated as rising from between 1,000,000 and 1,500,000 in the 3rd millennium BC to perhaps twice as many in the late 2nd millennium and 1st millennium BC. (Much higher levels of population were reached in Greco-Roman times.)

Nearly all of the people were engaged in agriculture and were probably tied to the land. All the land belonged in theory to the king, although in practice those living on it could not easily be removed and some categories of land could be bought and sold. Land was assigned to high officials to provide them with an income, and most categories of land paid substantial dues to the state, which had a strong interest in keeping it in agricultural use. Abandoned land was taken back into state ownership and reassigned for cultivation. The people who lived on and worked the

Ownership of land

land were not free to leave and were obliged to work it, but they were not slaves; most paid a proportion of their produce to major officials. Free citizens who worked the land on their own behalf did emerge; terms used for them tended originally to refer to poor people, although they were probably not in fact poor. Slavery was never very common, being restricted to captives and foreigners or to people who were forced by poverty or debt to sell themselves into service. Slaves sometimes were even married by members of their owners' families, so that in the long term those belonging to households tended to be assimilated into free society. In the New Kingdom (from about 1539 to 1075 BC), large numbers of captive slaves were acquired by major state institutions or incorporated into the army. Punitive treatment of foreign slaves or of native fugitives from their obligations included forced labour, exile (in, for example, the oases of the western desert), or compulsory enlistment in dangerous mining expeditions. Even nonpunitive employment such as quarrying in the desert was hazardous. The official record of one expedition shows a mortality rate of more than 10 percent.

Just as the Egyptians optimized agricultural production with simple means, their crafts and techniques, many of which originally came from Asia, were raised to extraordinary levels of perfection. The Egyptians' most striking technical achievement, massive stone building, also exploited the potential of a centralized state to mobilize a huge labour force, which was made available by efficient agricultural practices. Some of the technical and organizational skills involved were remarkable. The construction of the great pyramids of the 4th dynasty (*c.* 2575–*c.* 2465 BC) has yet to be fully explained and would be a major challenge to this day. This expenditure of skill contrasts with sparse evidence for an essentially neolithic way of living for the rural population of the time, while the use of flint tools persisted even in urban environments at least until the late 2nd millennium BC. Metal was correspondingly scarce, much of it being used for prestige rather than everyday purposes.

Family, marriage, and the role of women

In urban and elite contexts the Egyptian ideal was the nuclear family, but on the land and outside the central ruling group there is evidence for extended families. Egyptians were monogamous, and the choice of partners in marriage, for which no formal ceremony or legal sanction is known, did not follow a set pattern. Consanguineous marriage was not practiced during the Dynastic Period, except for the occasional marriage of a brother and sister within the royal family, and the practice may have been open only to kings or heirs to the throne. Divorce was in theory easy, but it was very costly. Women had a legal status only marginally inferior to that of men. They could own and dispose of property in their own right, and they could initiate divorce and other legal proceedings. They hardly ever held administrative office but increasingly were involved in religious cults as priestesses or "chantresses." Elite married women held the title "Mistress of the House," the precise significance of which is unknown. Lower down the social scale they probably worked on the land as well as in the house.

The uneven distribution of wealth, labour, and technology was related to the only partly urban character of society, especially in the 3rd millennium BC. The country's resources were not fed into numerous provincial towns but instead were concentrated to great effect around the capital—itself a dispersed string of settlements rather than a city—and focused on the central figure in society, the king. In the 3rd and early 2nd millennia the elite ideal, expressed in the decoration of private tombs, was manorial and rural. Not until much later did Egyptians have pronouncedly urban values.

The king and ideology: administration, art, and writing. In official terms, Egyptian society consisted of a descending hierarchy of the gods, the king, the dead, and humanity (by which was understood chiefly the Egyptians). Of these groups, only the king was single, and hence he was individually more prominent than any of the others. A text that summarizes the king's role states that he "is on earth for ever and ever, judging mankind and propitiating the gods, and setting order [*ma'at*, a central concept] in place of disorder. He gives offerings to the gods and mortuary offerings to the spirits [the blessed dead]." The king was a god, but not in any simple or unqualified sense. His divinity accrued to him from his office and was reaffirmed through rituals, but it was vastly inferior to that of major gods; he was god rather than man by virtue of his potential, which was immeasurably greater than that of any human being. To humanity, he manifested the gods on earth, a conception that was elaborated in a complex web of metaphor and doctrine; less directly, he represented humanity to the gods. The text quoted above also gives great prominence to the dead, for whom the living performed a cult and who could intervene in human affairs; in many periods the chief visible expenditure and focus of display of nonroyal individuals, as of the king, was on provision for the tomb and the next world. Egyptian kings are commonly called pharaohs, following the usage of the Old Testament. The term pharaoh, however, is derived from the Egyptian *per 'aa* ("great estate") and goes back to the designation of the royal palace as an institution. This term for palace was used increasingly from about 1400 BC as a way of referring to the living king; in earlier times it was rare.

The king's relation to the gods

Rules of succession to the kingship are poorly understood. The common conception that the heir to the throne had to marry his predecessor's oldest daughter has been disproved; kingship did not pass through the female line. The choice of queen seems to have been free: often the queen was a close relative of the king, but she also might be unrelated to him. In the New Kingdom, for which evidence is abundant, each king had a queen with distinctive titles, as well as a number of minor wives.

Sons of the queen seem to have been the preferred successors to the throne, but other sons could also become king. In many cases the successor was the eldest (surviving) son, and such a pattern of inheritance agrees with more general Egyptian values, but often he was some other relative, or was completely unrelated. New Kingdom texts depict, after the event, how kings were appointed heirs either by their predecessors or by divine oracles, and such may have been the pattern when there was no clear successor. From the middle of the 5th dynasty (*c.* 2450 BC) to the 19th (1292–1190 BC) there is no certain attestation of a prince in the reign of his brother; rival claimants, therefore, must have been eliminated or silenced after one of them had succeeded. Dissent and conflict are suppressed from public sources. From the Late Period (664–332 BC), when sources are more diverse and patterns less rigid, numerous usurpations and interruptions to the succession are known; they probably had many forerunners.

The king's position changed gradually from that of an absolute monarch at the centre of a small ruling group who were mostly his kin to that of the head of a bureaucratic state—in which his rule was still absolute—based on officeholding and, in theory, on free competition and merit. By the 5th dynasty, fixed institutions were added to the force of tradition and the regulation of personal contact as brakes on autocracy, but the charismatic and superhuman power of the king remained vital.

The bureaucratic elite

The elite of administrative officeholders received their positions and commissions from the king, whose general role as judge over humanity they put into effect. They commemorated their own justice and concern for others, especially their inferiors, and recorded their own exploits and ideal conduct of life in inscriptions for others to see. Thus the position of the elite was affirmed by reference to the king, to their prestige among their peers, and to their conduct toward their subordinates, justifying to some extent the fact that they—and still more the king—appropriated much of the country's surplus production for their own benefit.

These attitudes and their potential dissemination through society counterbalanced inequality, but how far they were accepted cannot be known. The core group of wealthy officeholders numbered at most a few hundred, and the administrative class of minor officials and scribes, most of whom could not afford to leave memorials or inscriptions, perhaps 5,000. With their dependents, these two groups formed perhaps 5 percent of the early population. Monu-

ments and inscriptions commemorated no more than one in a thousand people.

According to royal ideology, the king appointed the elite on the basis of merit, and in ancient conditions of high mortality the elite had to be open to recruits from outside. In addition, royal caprice resulted in many falls from favour, especially in the 18th dynasty (1539–1292 BC). There was, however, also an ideal that a son should succeed his father. In periods of weak central control this principle predominated, and in the Late Period the whole society became more rigid and stratified.

Use of hieroglyphs

Writing was a major instrument in the centralization of the Egyptian state and its self-presentation. The two basic forms of writing, hieroglyphs, which were used for monuments and display, and the cursive form known as hieratic, were invented at much the same time in late predynastic Egypt (*c.* 3000 BC). Writing was chiefly used for administration and until about 2650 BC no continuous texts were recorded; the only literary texts written down before the early Middle Kingdom (*c.* 1950 BC) seem to have been lists of important traditional information and possibly medical treatises. The use and potential of writing were restricted both by the rate of literacy, which was probably well below 1 percent, and expectations of what writing might do. Hieroglyphic writing was publicly identified with Egypt. Perhaps because of this association with a single powerful state, its language, and its culture, Egyptian writing was seldom adapted to write other languages; in this it contrasts with the cuneiform script of the relatively uncentralized, multilingual Mesopotamia. Nonetheless, Egyptian hieroglyphs probably served in the middle of the 2nd millennium BC as the model from which the alphabet, ultimately the most widespread of all writing systems, evolved.

The dominant visible legacy of ancient Egypt is in works of architecture and representational art. Until the Middle Kingdom, most of these were mortuary: royal tomb complexes, including pyramids and mortuary temples, and private tombs. There were also temples dedicated to the cult of the gods throughout the country, but most of these were modest structures. From the beginning of the New Kingdom (*c.* 1539 BC), temples of the gods became the principal monuments; royal palaces and private houses, which are very little known, were less important. Temples and tombs were ideally executed in stone with relief decoration on their walls and were filled with stone and wooden statuary, inscribed and decorated stelae (freestanding small stone monuments), and, in their inner areas, composite works of art in precious materials. The design of the monuments and their decoration goes back in essence to the beginning of the historical period and presents an ideal, sanctified cosmos. Little in it is related to the everyday world and, except in palaces, works of art may have been rare outside temples and tombs. Decoration may record real historical events, rituals, or the official titles and careers of individuals, but its prime aim is the more general assertion of values, and the information presented must be evaluated for its plausibility and compared with other evidence. Some of the events depicted in relief on royal monuments were certainly fictitious.

Temples and tombs and their decoration

The highly distinctive Egyptian method of rendering nature and artistic style were also creations of early times and can be seen in most works of Egyptian art. In content, these are hierarchically ordered so that the most important figures, the gods and the king, are shown together, while before the New Kingdom gods seldom occur in the same context as humanity. The decoration of a nonroyal tomb characteristically shows the tomb's owner with his subordinates, who administer his land and present him with its produce. The tomb owner is also typically depicted hunting in the marshes, a favourite pastime of the elite that may additionally symbolize passage into the next world. The king and the gods are absent in nonroyal tombs, and overtly religious matter is restricted to rare scenes of mortuary rituals and journeys and to textual formulas. Temple reliefs, in which king and gods occur freely, show the king defeating his enemies, hunting, and especially offering to the gods, who in turn confer benefits upon him. Human beings are present at most as minor figures supporting the king. On both royal and nonroyal monuments an ideal world is represented in which all are beautiful and everything goes well; only minor figures may have physical imperfections.

This artistic presentation of values originated at the same time as writing, but before the latter could record continuous texts or complex statements. Some of the earliest continuous texts of the 4th and 5th dynasties show an awareness of an ideal past that the present could only aspire to emulate. A few "biographies" of officials allude to strife, but more nuanced discussion occurs first in literary texts of the Middle Kingdom. The texts consist of stories, dialogues, lamentations, and especially instructions on how to live a good life, and they supply a rich commentary on the more one-dimensional rhetoric of public inscriptions. Literary works were written in all the main later phases of the Egyptian language—Middle Egyptian; the "classical" form of the Middle and New kingdoms, continuing in copies and inscriptions into Roman times; Late Egyptian, from the 19th dynasty to about 700 BC; and demotic (texts from the 4th century BC to the 3rd century AD)—but many of the finest and most complex are among the earliest.

Literary works also included treatises on mathematics, astronomy, medicine, and magic, as well as various religious texts and canonical lists that classified the categories of creation (probably the earliest genre, going back to the beginning of the Old Kingdom, *c.* 2575 BC, or even a little earlier). Among these texts, little is truly systematic, a notable exception being a medical treatise on wounds. The absence of systematic enquiry contrasts with Egyptian practical expertise in such fields as surveying, which was used both for orienting and planning buildings to remarkably fine tolerances and for the regular division of fields after the inundation; the Egyptians also surveyed and established the dimensions of their entire country by the beginning of the Middle Kingdom. These precise tasks required both knowledge of astronomy and highly ingenious techniques, but they apparently were achieved with little theoretical analysis.

Administration and law

Whereas in the earliest periods Egypt seems to have been administered almost as the personal estate of the king, by the central Old Kingdom it was divided into about 35 nomes, or provinces, each with its own officials. Administration was concentrated at the capital, where most of the central elite lived and died. In the nonmonetary Egyptian economy, its essential functions were the collection, storage, and redistribution of produce; the drafting and organization of manpower for specialized labour, probably including irrigation and flood protection works, and major state projects; and the supervision of legal matters. Administration and law were not fully distinct and both depended ultimately on the king. The settlement of disputes was in part an administrative task, for which the chief guiding criterion was precedent, while contractual relations were regulated by the use of standard formulas. State and temple both partook in redistribution and held massive reserves of grain; temples were economic as well as religious institutions. In periods of decentralization similar functions were exercised by local grandees. Markets had only a minor role, and craftsmen were employees who normally traded only what they produced in their free time. The wealthiest officials escaped this pattern to some extent by receiving their income in the form of land and maintaining large establishments that included their own specialized workers.

The essential medium of administration was writing, reinforced by personal authority over the nonliterate 99 percent of the population; texts exhorting the young to be scribes emphasize that the scribe commanded while the rest did the work. Most officials (almost all of whom were men) held several offices and accumulated more as they progressed up a complex ranked hierarchy, at the top of which was the vizier, the chief administrator and judge. The vizier reported to the king, who in theory retained certain powers, such as authority to invoke the death penalty, absolutely.

Before the Middle Kingdom, the civil and the military were not sharply distinguished. Military forces consisted

of local militias under their own officials and included foreigners, and nonmilitary expeditions to extract minerals from the desert or to transport heavy loads through the country were organized in similar fashion. Until the New Kingdom there was no separate priesthood. Holders of civil office also had priestly titles, and priests had civil titles. Often priesthoods were sinecures: their chief significance was the income they brought. The same was true of the minor civil titles accumulated by high officials. At a lower level, minor priesthoods were held on a rotating basis by "laymen" who served every fourth month in temples. State and temple were so closely interconnected that there was no real tension between them before the late New Kingdom.

Sources, calendars, and chronology. For all but the last century of Egyptian prehistory, whose neolithic and later phases are normally termed "predynastic," evidence is exclusively archaeological; later native sources have only mythical allusions to such remote times. The dynastic period of native Egyptian rulers is generally divided into 30 dynasties, following the *Aegyptiaca* of the Greco-Egyptian writer Manetho of Sebennytos (early 3rd century BC), excerpts of which are preserved in later writers. Manetho apparently organized his dynasties by the capital cities from which they ruled, but several of his divisions also reflect political or dynastic changes, that is, changes of the party holding power. He gave the lengths of reign of kings or of entire dynasties and even longer periods. Because of textual corruption and a tendency to inflation, his figures cannot be used to reconstruct chronology and reign lengths without supporting evidence and analysis.

Basis for outline of dynasties

Manetho's prime sources were earlier Egyptian king lists, the organization of which he imitated. The most significant preserved example of a king list is the Turin Canon, a fragmentary papyrus in the Egyptian Museum in Turin, Italy, which originally listed all kings of the 1st through the 17th dynasty, preceded by a mythical dynasty of gods and one of the "spirits, followers of Horus." The document gave reign lengths for individual kings, as well as totals for some dynasties and longer periods.

In early periods the kings' years of reign were not given numbers but were named for salient events, and lists were made of the names. More extensive details were added to the lists for the 4th and 5th dynasties, when dates were assigned according to biennial cattle censuses numbered through each king's reign. Fragments of such lists are preserved on the Palermo Stone, an inscribed piece of basalt (at the Regional Museum of Archaeology in Palermo, Italy), and related pieces in the Cairo Museum and University College London; these are probably all parts of a late copy of an original document.

Calculating dates for Egyptian prehistory

The Egyptians did not date by eras longer than the reign of a single king, so a historical framework must be created from totals of reign lengths, which are then related to astronomical data that may allow whole periods to be fixed precisely. This is done through references to astronomical events and correlations with the three calendars in use in Egyptian antiquity. All dating was by a civil calendar, derived from the lunar calendar, which was introduced in the first half of the 3rd millennium BC. The civil year had 365 days and started in principle when Sirius, or the Dog Star—also known as Sothis (Ancient Egyptian: Il Sopdet)—became visible above the horizon after a period of absence, which at that time occurred some weeks before the Nile began to rise for the inundation. Every four years the civil year advanced one day in relation to the Julian year (with $365\frac{1}{4}$ days), and after a cycle of about 1,460 years it would again agree with the lunisolar calendar. Religious ceremonies were organized according to two lunar calendars that had months of 29 or 30 days, with extra, intercalary months every three years or so.

Four mentions of the rising of Sirius (generally known as Sothic dates) are preserved in texts from the 3rd to the 1st millennia, but by themselves these references cannot yield an absolute chronology. Such a chronology can be computed from larger numbers of lunar dates and cross-checked from solutions for the observations of Sirius. Various chronologies are in use, however, differing by up to 40 years for the 2nd millennium BC and by more than a century for the beginning of the 1st dynasty. The chronologies offered in most publications up to 1985 have been disproved for the Middle and New kingdoms by a restudy of the evidence for the Sothic and especially the lunar dates. For the 1st millennium, dates in the Third Intermediate Period are approximate; a supposed fixed year of 945 BC, based on links with the Old Testament, turns out to be variable by a number of years. Late Period dates (664–332 BC) are almost completely fixed. Before the 12th dynasty, plausible dates for the 11th can be computed backward, but for earlier times dates are approximate. A total of 955 years for the 1st through the 8th dynasty in the Turin Canon has been used to assign a date of about 3100 BC for the beginning of the 1st dynasty, but this requires excessive average reign lengths, and an estimate of 2925 BC is preferable. Radiocarbon and other scientific dating of samples from Egyptian sites have not improved on, or convincingly contested, computed dates. Recent work on radiocarbon dates from Egypt does, however, yield results encouragingly close to dates computed in the manner described above.

King lists and astronomy give only a chronological framework. A vast range of archaeological and inscriptional sources for Egyptian history survives, but none of it was produced with the interpretation of history in mind. No consistent political history of ancient Egypt can be written. The evidence is very unevenly distributed, there are gaps of many decades, and in the 3rd millennium BC no continuous royal text recording historical events was inscribed. Private biographical inscriptions of all periods from the 5th dynasty (*c.* 2465–*c.* 2325 BC) to the Roman conquest (30 BC) record individual involvement in events but are seldom concerned with their general significance. Royal inscriptions from the 12th dynasty (1938–1756 BC) to Ptolemaic times aim to present a king's actions according to an overall conception of "history," in which he is the re-creator of the order of the world and the guarantor of its continued stability or its expansion. The goal of his action is not to serve humanity but the gods, while nonroyal individuals may relate their own successes to the king in the first instance and sometimes to the gods. Only in the decentralized intermediate periods did the nonroyal recount internal strife. Kings did not mention dissent in their texts unless it came at the beginning of a reign or a phase of action and was quickly and triumphantly overcome in a reaffirmation of order. Such a schema often dominates the factual content of texts, and it creates a strong bias toward recording foreign affairs, because in official ideology there is no internal dissent after the initial turmoil is over. "History" is as much a ritual as a process of events; as a ritual, its protagonists are royal and divine. Only in the Late Period did these conventions weaken significantly. Even then, they were retained in full for temple reliefs, where they kept their vitality into Roman times.

Despite this idealization, the Egyptians were well aware of history, as is clear from their king lists. They divided the past into periods comparable with those used by Egyptologists, and they evaluated the personalities of rulers as the founders of epochs, for salient exploits, or, especially in folklore, for their bad qualities. The Demotic Chronicle, a text of the Ptolemaic period, purports to foretell the bad end that would befall numerous Late Period kings as divine retribution for their wicked actions.

The recovery and study of ancient Egypt. European interest in ancient Egypt was strong in Roman times and revived in the Renaissance, when the small amount of information provided by visitors to the country was compensated for by the wealth of Egyptian remains in the city of Rome. Views of Egypt were dominated by the classical tradition that it was the land of ancient wisdom; this wisdom was thought to inhere in the hieroglyphic script, which was believed to impart profound symbolic ideas, not—as it in fact does—the sounds and words of texts. Between the 15th and 18th centuries, Egypt had a minor but significant position in general views of antiquity, and its monuments gradually became better known through the work of scholars in Europe and travelers in the country itself; the finest publications of the latter were by Richard Pococke, Frederik Ludwig Norden, and Carsten Niebuhr,

all of whose works in the 18th century helped to stimulate an Egyptian revival in European art and architecture. Coptic, the Christian successor of the ancient Egyptian language, was studied from the 17th century, notably by Athanasius Kircher, for its potential to provide the key to Egyptian.

Napoleon's expedition to and short-lived conquest of Egypt in 1798 was the culmination of 18th-century interest in the East. The expedition was accompanied by a team of scholars who recorded the ancient and contemporary country, issuing in 1809–28 the *Description de l'Égypte*, the most comprehensive study to be made before the decipherment of the hieroglyphic script. The Rosetta Stone, which bears a decree of Ptolemy V Epiphanes in hieroglyphs, demotic, and Greek, was discovered during the expedition and was ceded to the British after the French capitulation; it became the property of the British Museum in London. This document greatly assisted the decipherment, accomplished by Jean-François Champollion in 1822.

Discovery of the Rosetta Stone

The Egyptian language revealed by the decipherment and more than 150 years of study is a member of the Afro-Asiatic, or Hamito-Semitic, language family. The Egyptian is closest to the family's Semitic branch but is distinctive in many respects. During several millennia it changed greatly. The script does not write vowels. Because Greek forms for royal names were known from Manetho long before the Egyptian forms became available, those used to this day are a mixture of Greek and Egyptian.

In the first half of the 19th century vast numbers of antiquities were exported from Egypt, forming the nucleus of collections in many major museums. These were removed rather than excavated, inflicting, together with the economic development of the country, colossal damage on ancient sites. At the same time, many travelers and scholars visited the country and recorded the monuments. The most important, and remarkably accurate, record was produced by the Prussian expedition led by Karl Richard Lepsius, in 1842–45, which explored sites as far south as the central Sudan.

Egyptology as a scholarly pursuit

In the mid-19th century Egyptology developed as a subject in France and in Prussia. The Antiquities Service and a museum of Egyptian antiquities were established in Egypt by the French Egyptologist Auguste Mariette, a great excavator who attempted to preserve sites from destruction, and the Prussian Heinrich Brugsch made great progress in the interpretation of texts of many periods and published the first major Egyptian dictionary. In 1880 Flinders (later Sir Flinders) Petrie began more than 40 years of methodical excavation, which created an archaeological framework for all the chief periods of Egyptian culture except for remote prehistory. Petrie was the initiator of much in archaeological method, but he was later surpassed by George Andrew Reisner, who excavated for American institutions from 1899 to 1937. The greatest late 19th-century Egyptologist was Adolf Erman of Berlin, who put the understanding of the Egyptian language on a sound basis and wrote general works that for the first time organized what was known about the earlier periods.

From the 1890s on, complete facsimile copies of Egyptian monuments have been published, providing a separate record that becomes more vital as the originals decay. The pioneer of this epigraphy was Norman de Garis Davies, who was joined in the 1920s by the Oriental Institute of the University of Chicago and other enterprises. Many scholars are now engaged in epigraphy.

In the first half of the 20th century some outstanding archaeological discoveries were made: Howard Carter uncovered the tomb of Tutankhamen in 1922; Pierre Montet found the tombs of 21st–22nd-dynasty kings at Tanis in 1939–44; and W.B. Emery and L.P. Kirwan found tombs of the Ballānah culture (the 4th through the 6th century AD) in Nubia in 1931–34. The last of these was part of the second survey of Lower Nubia in 1929–34, which preceded the second raising of the Aswān Dam. This was followed in the late 1950s and '60s by an international campaign to excavate and record sites in Egyptian and Sudanese Nubia before the completion of the Aswān High Dam in 1970. Lower Nubia is now one of the most thoroughly explored archaeological regions of the world. Most of its many temples have been moved, either to higher ground nearby, as happened to Abu Simbel and Philae, or to quite different places, including various foreign museums. The campaign also had the welcome consequence of introducing a wide range of archaeological expertise to Egypt, so that standards of excavation and recording in the country have risen greatly.

Excavation and survey of great importance continues in many places. For example, at Saqqārah, part of the necropolis of the ancient city of Memphis, new areas of the Sarapeum have been uncovered with rich finds, and a major New Kingdom necropolis is being thoroughly explored. The site of ancient Memphis itself has been systematically surveyed, its position in relation to the ancient course of the Nile has been established, and urban occupation areas have been studied in detail for the first time.

Egyptology is, however, a primarily interpretive subject. There have been outstanding contributions, for example in art, for which Heinrich Schäfer established the principles of the rendering of nature, and in language. New light has been cast on texts, the majority of which are written in a simple metre that can serve as the basis of sophisticated literary works. The physical environment, social structure, kingship, and religion are other fields in which great advances have been made, while the reconstruction of the outline of history is constantly being improved in detail.

THE PREDYNASTIC AND EARLY DYNASTIC PERIODS

Predynastic Egypt. The peoples of predynastic Egypt were the successors of the Paleolithic inhabitants of northeastern Africa, who had spread over much of its area; during wet phases they had left remains in regions as inhospitable as the Great Sand Sea. The final desiccation of the Sahara was not complete until the end of the 3rd millennium BC; over thousands of years people must have migrated from there to the Nile Valley, the environment of which improved as it dried out. In this process, the decisive change from the nomadic hunter-gatherer way of life of Paleolithic times to settled agriculture has not so far been identified. Some time after 5000 BC the raising of crops was introduced, probably on a horticultural scale, in small, local cultures that seem to have penetrated southward through Egypt into the oases and the Sudan. Several of the basic food plants that were grown are native to the Near East, so the new techniques probably spread from there. No large-scale migration need have been involved, and the cultures were at first largely self-contained. The preserved evidence for them is unrepresentative, because it comes from the low desert, where relatively few people lived; as later, most people probably settled in the Valley and Delta.

The earliest known Neolithic cultures in Egypt have been found at Marimda Banī Salāma, on the southwest edge of the Delta, and farther to the southwest, in the Fayyūm. The site at Marimda Banī Salāma, which dates to the 6th–5th millennia BC, gives evidence of settlement and shows that cereals were grown. In the Fayyūm, where evidence dates to the 5th millennium BC, the settlements were near the shore of Lake Qārūn, and the settlers engaged in fishing. Marimda is a very large site that was occupied for many centuries. The inhabitants lived in lightly-built huts; they may have buried their dead within their houses, but areas where burials have been found may not have been occupied by dwellings at the same time. Pottery was used in both cultures. In addition to these Egyptian Neolithic cultures, others have been identified in the Western Desert, in the Second Cataract area, and north of Khartoum. Some of these are as early as the Egyptian ones, while others overlapped with the succeeding Egyptian predynastic cultures.

Tasian and Badarian cultures

In Upper Egypt, between Asyūṭ and Luxor, have been found the Tasian culture (named after Dayr Tasa) and the Badarian culture (named after al-Badārī); these date from the late 5th millennium BC. Most of the evidence for them comes from cemeteries, where the burials included fine black-topped red pottery, ornaments, some copper objects, and glazed steatite beads. The most characteristic predynastic luxury objects, slate palettes for grinding cos-

metics, occur for the first time in this period. The burials show little differentiation of wealth and status and seem to belong to a peasant culture without central political organization.

Probably contemporary with both predynastic and dynastic times are thousands of rock drawings of a wide range of motifs, including boats, found throughout the Eastern Desert, in Lower Nubia, and as far west as Mount 'Uwaynāt, which stands near modern Egypt's borders with Libya and The Sudan in the southwest. The drawings show that nomads were common throughout the desert, probably down to the late 3rd millennium BC, but they cannot be dated precisely; they may all have been produced by nomads, or inhabitants of the Nile Valley may often have penetrated the desert and made drawings.

Naqādah I

Naqādah I, named after the major site of Naqādah but also called Amratian after al-'Amirah, is a distinct phase that succeeded Badarian and has been found as far south as Kawm al-Aḥmar (Hierakonpolis; ancient Egyptian Nekhen), near the sandstone barrier of Jabal al-Silsila, which was the cultural boundary of Egypt in predynastic times. Naqādah I differs from Badarian in its density of settlement and in the typology of its material culture, but hardly at all in the social organization implied by finds. Burials were in shallow pits in which the bodies faced to the west, like those of later Egyptians. Notable types of material found in graves are fine pottery decorated with representational designs in white on red, figurines of men and women, and hard stone mace-heads that are the precursors of important late predynastic objects.

Naqādah II

Naqādah II, also known as Gerzean after al-Girza, is the most important predynastic culture. The heartland of its development was the same as that of Naqādah I, but it spread gradually throughout the country. South of Jabal al-Silsila, sites of the culturally similar Nubian A Group are found as far as the Second Cataract and beyond; these have a long span, continuing as late as the Egyptian Early Dynastic Period. During Naqādah II, large sites developed at Kawm al-Aḥmar, Naqādah, and Abydos, showing by their size the concentration of settlement, as well as exhibiting increasing differentiation in wealth and status. Few sites have been identified between Asyūṭ and the Fayyūm, and this region may have been sparsely settled, perhaps supporting a pastoral rather than agricultural population. Near modern Cairo, at al-'Umāri, Ma'ādi, and Wādī Digla, and stretching as far south as the latitude of the Fayyūm, are sites of a separate, contemporary culture. Ma'ādi was an extensive settlement that traded with the Near East and probably acted as an intermediary for transmitting goods to the south. In this period, imports of lapis lazuli provide evidence that trade networks extended as far afield as Afghanistan.

The material culture of Naqādah II included increasing numbers of prestige objects. The characteristic mortuary pottery is made of buff desert clay, principally from around Qena, and is decorated in red with pictures of uncertain meaning showing boats, animals, and scenes with human figures. Stone vases, many made of hard stones that come from remote areas of the Eastern Desert, are common and of remarkable quality, and cosmetic palettes display elaborate designs, with outlines in the form of animals, birds, or fish. Flint was worked with extraordinary skill to produce large ceremonial knives of a type that continued in use during dynastic times.

Sites of late Naqādah II (sometimes termed Naqādah III) are found throughout Egypt, including the Memphite area and the Delta, and appear to have replaced the local Lower Egyptian cultures. Links with the Near East intensified and some distinctively Mesopotamian motifs and objects were briefly in fashion in Egypt. The cultural unification of the country probably accompanied a political unification, but this must have proceeded in stages and cannot be reconstructed in detail. In an intermediate stage, local states may have formed at Kawm al-Aḥmar, Naqādah, and Abydos, and in the Delta at such sites as Buto (modern Tall al-Farā'īn) and Sais. Ultimately, Abydos became preeminent; its late predynastic cemetery of Umm al-Qa'āb was extended to form the burial place of the kings of the 1st dynasty. In the latest predynastic period, objects bearing written symbols of royalty were deposited throughout the country, and primitive writing also appeared in marks on pottery. Because the basic symbol for the king, a falcon on a decorated palace facade, hardly varies, these objects are thought to have belonged to a single line of kings or a single state, and not to a set of small states. This symbol became the royal Horus name, the first element in a king's titulary, which presented the reigning king as the manifestation of an aspect of the god Horus, the leading god of the country. Over the next few centuries several further definitions of the king's presence were added to this one.

Thus at this time Egypt seems to have been a state unified under kings who introduced writing and the first bureaucratic administration. These kings, who could have ruled for more than a century, may correspond with a set of names preserved on the Palermo Stone, but no direct identification can be made between them. The latest was probably Narmer, whose name has been found near Memphis, at Abydos, on a ceremonial palette and mace-head from Kawm al-Aḥmar, and at the Palestinian sites of Tall Gat and 'Arad. The relief scenes on the palette show him wearing the two chief crowns of Egypt and defeating northern enemies, but these probably are stereotyped symbols of the king's power and role and not records of specific events of his reign. They demonstrate that the position of the king in society and its presentation in mixed pictorial and written form had been elaborated by this date.

During this time Egyptian artistic style and conventions were formulated, together with writing. The process led to a complete and remarkably rapid transformation of material culture, so that many dynastic Egyptian prestige objects hardly resemble their forerunners.

The Early Dynastic Period (c. 2925–c. 2575 BC). *The 1st dynasty (c. 2925–c. 2775 BC).* The beginning of the historical period is characterized by the introduction of written records in the form of regnal year names—the records that later were collected in documents such as the Palermo Stone. The first king of Egyptian history, Menes, is therefore a creation of the later record, not the actual unifier of the country; he is known from Egyptian king lists and from classical sources and is credited with irrigation works and with founding the capital, Memphis. On small objects from this time, one of them dated to the important king Narmer but certainly mentioning a different person, there are two possible mentions of a "Men" who may be the king Menes. If these do name Menes, he was probably the same person as Aha, Narmer's probable successor, who was then the founder of the 1st dynasty. Changes in the naming patterns of kings reinforce the assumption that a new dynasty began with his reign. Aha's tomb at Abydos is altogether more grandiose than previously built tombs, while the first of a series of massive tombs at Ṣaqqārah, next to Memphis, supports the tradition that the city was founded then as a new capital. This shift from Abydos is the culmination of intensified settlement in the crucial area between the Valley and the Delta, but Memphis did not yet overcome the traditional pull of its predecessor: the large tombs at Ṣaqqārah appear to belong to high officials, while the kings were buried at Abydos in tombs without formal superstructures. Their mortuary cult may have been conducted in flimsy buildings in designated areas nearer the cultivation, around which a number of burials of important individuals were grouped.

Introduction of written records

In the late predynastic period and the first half of the 1st dynasty, Egypt extended its influence into southern Palestine and probably Sinai and conducted a campaign as far as the Second Cataract. The First Cataract area, with its centre on Elephantine, an island in the Nile opposite the modern town of Aswān, was permanently incorporated into Egypt, but Lower Nubia was not.

Between late predynastic times and the 4th dynasty—and probably early in the period—the Nubian A Group came to an end. There is some evidence that political centralization was in progress around Qustul, but this did not lead to any further development and may indeed have prompted a preemptive strike by Egypt. For Nubia, the malign proximity of the largest state of the time stifled

advancement. During the 1st dynasty, writing spread gradually, but because it was used chiefly for administration, the records, which were kept within the floodplain, have not survived. The artificial writing medium of papyrus was invented by the middle of the 1st dynasty. There was a surge in prosperity, and thousands of tombs of all levels of wealth have been found throughout the country. The richest contained magnificent goods in metal, ivory, and other materials, the most widespread luxury products being extraordinarily fine stone vases. The high point of 1st-dynasty development was the long reign of Den (flourished *c.* 2850 BC).

Elements of the kings' names

During the 1st dynasty three titles were added to the royal Horus name: "Two Ladies," an epithet presenting the king as making manifest an aspect of the protective goddesses of the south (Upper Egypt) and the north (Lower Egypt); "Golden Horus," the precise meaning of which is unknown; and "Dual King," a ranked pairing of the two basic words for king, later associated with Upper and Lower Egypt. These titles were followed by the king's own birth name, which in later centuries was written in a cartouche.

The 2nd dynasty (c. 2775–c. 2650 BC). From the end of the 1st dynasty there is evidence of rival claimants to the throne. One line may have become the 2nd dynasty, whose first king's Horus name, Hetepsekhemwy, means "peaceful in respect of the two powers" and may allude to the conclusion of strife between two factions or parts of the country, to the antagonistic gods Horus and Seth, or to both. Hetepsekhemwy and his successor, Reneb, moved their burial places to Ṣaqqārah; the tomb of the third king, Nynetjer, has not been found. The second half of the dynasty was a time of conflict and rival lines of kings, some of whose names are preserved on stone vases from the 3rd-dynasty Step Pyramid at Ṣaqqārah or in king lists. Among these contenders, Peribsen took the title of Seth instead of Horus and was probably opposed by Horus Khasekhem, whose name is known only from Kawm al-Aḥmar and who used the programmatic epithet "effective sandal against evil." The last ruler of the dynasty combined the Horus and Seth titles to form the Horus-and-Seth Khasekhemwy, "arising in respect of the two powers," to which was added "the two lords are at peace in him." Khasekhemwy was probably the same person as Khasekhem after the successful defeat of his rivals, principally Peribsen. Both Peribsen and Khasekhemwy had tombs at Abydos, and the latter also built a monumental brick funerary enclosure near the main temple (there were two further such enclosures).

The 3rd dynasty (c. 2650–c. 2575 BC). There were links of kinship between Khasekhemwy and the 3rd dynasty, but the change between them is marked by a definitive shift of the royal burial place to Memphis. Its first king, Sanakhte, is attested in reliefs from Maghāra in Sinai. His successor, Djoser (Horus name Netjerykhet), was one of the outstanding kings of Egypt. His Step Pyramid at Ṣaqqārah is both the culmination of an epoch and—as the first large all-stone building, many times larger than anything attempted before—the precursor of later achievements. The pyramid is set in a much larger enclosure than that of Khasekhemwy at Abydos and contains reproductions in stone of ritual structures that had previously been built of perishable materials. Architectural details of columns, cornices, and moldings provided many models for later development. The masonry techniques look to brickwork for models and show little concern for the structural potential of stone. The pyramid itself evolved through numerous stages from a flat mastaba (an oblong tomb with a burial chamber dug beneath it, common at earlier nonroyal sites) into a six-stepped, almost square pyramid. There was a second, symbolic tomb with a flat superstructure on the south side of the enclosure; this probably substituted for the traditional royal burial place of Abydos. The king and some of his family were buried deep under the pyramid, where tens of thousands of stone vases were deposited, a number bearing inscriptions of the first two dynasties. Thus, in perpetuating earlier forms in stone and burying this material, Djoser invoked the past in support of his innovations.

Djoser's Step Pyramid at Ṣaqqārah

Djoser's name was famous in later times and his monument was studied in the Late Period. Imhotep, whose title as a master sculptor is preserved from the Step Pyramid complex, may have been its architect; he lived on into the next reign. His fame also endured, and in the Late Period he was deified and became a god of healing. In Manetho's history he is associated with reforms of writing and this may reflect a genuine tradition, for hieroglyphs were simplified and standardized at this time.

Djoser's successor, Sekhemkhet, planned a still more grandiose step pyramid complex, and a later king, Khaba, began one at Zawyat al-ʿAryan, a few miles south of Giza. The burial place of the last king of the dynasty, Huni, is unknown. It has often been suggested that he built the pyramid of Maydūm, but this probably was the work of his successor, Snefru. Inscribed material naming 3rd-dynasty kings is known from Maghāra to Elephantine but not from the Near East or Nubia.

The organizational achievements of the 3rd dynasty are reflected in its principal monument, whose message of centralization and concentration of power is reinforced in a negative sense by the archaeological record. Outside the vicinity of Memphis, the Abydos area continued to be important, and four enormous tombs, probably of high officials, were built at the nearby site of Bayt Khallaf; there were small, nonmortuary step pyramids throughout the country, some of which may date to the 4th dynasty. Otherwise, little evidence comes from the provinces, from which wealth must have flowed to the centre, leaving no rich local elite. By the 3rd dynasty the rigid structure of the later nomes, or provinces, which formed the basis of Old Kingdom administration, had been created, and the imposition of its uniform pattern may have impoverished local centres. Tombs of the elite at Ṣaqqārah, notably those of Hezyre and Khabausokar, contained artistic masterpieces that look forward to the Old Kingdom.

THE OLD KINGDOM (c. 2575–c. 2130 BC) AND THE FIRST INTERMEDIATE PERIOD (c. 2130–1938 BC)

The Old Kingdom. *The 4th dynasty (c. 2575–c. 2465 BC).* The first king of the 4th dynasty, Snefru, probably built the step pyramid of Maydūm and then modified it to form the first true pyramid. Due west of Maydūm was the small step pyramid of Saylah, in the Fayyūm, at which Snefru also worked. He built two pyramids at Dahshūr; the southern of the two is known as the Bent Pyramid because its upper part has a shallower angle of inclination than its lower part. This difference may be due to structural problems or may have been planned from the start, in which case the resulting profile may reproduce a solar symbol of creation. The northern Dahshūr pyramid, the later of the two, has the same angle of inclination as the upper part of the Bent Pyramid and a base area exceeded only by that of the Great Pyramid. Both pyramids had mortuary complexes attached to them. Snefru's building achievements were thus at least as great as those of any later king and introduced a century of unparalleled construction.

Snefru's monuments

In a long perspective, the 4th dynasty was an isolated phenomenon, a period when the potential of centralization was realized to its utmost and a disproportionate amount of the state's resources was used on the kings' mortuary provisions, almost certainly at the expense of general living standards. No significant 4th-dynasty sites have been found away from the Memphite area. Tomb inscriptions show that high officials were granted estates scattered over many nomes, especially in the Delta. This pattern of landholding may have avoided the formation of local centres of influence while encouraging intensive exploitation of the land. People who worked on these estates were not free to move, and they paid a high proportion of their earnings in dues and taxes. The building enterprises must have relied on drafting vast numbers of men, probably after the harvest had been gathered in the early summer and during part of the inundation.

Snefru's was the first king's name that was regularly written inside the cartouche, an elongated oval that is one of the most characteristic Egyptian symbols. The cartouche itself is older and was shown as a gift bestowed by gods on

the king, signifying long duration on the throne. It soon acquired associations with the sun, so that its first use by the builder of the first true pyramid, which is probably also a solar symbol, is not coincidental.

The Great Pyramid at Giza

Snefru's successor, Khufu (Cheops), built the Great Pyramid at Giza, to which were added the slightly smaller second pyramid of one of Khufu's sons, Khafre (more correctly Rekhaef, the Chephren of Greek sources), and that of Menkaure (Mycerinus). Khufu's successor, his son Redjedef, began a pyramid at Abū Ruwaysh, and a king of uncertain name began one at Zawyat al-'Aryan. The last known king of the dynasty (there was probably one further), Shepseskaf, built a monumental mastaba at south Ṣaqqārah and was the only Old Kingdom ruler not to begin a pyramid. These works, especially the Great Pyramid, show a great mastery of monumental stoneworking: individual blocks were large or colossal and were very accurately fitted to one another. Surveying and planning also were carried out with remarkable precision.

Apart from the colossal conception of the pyramids themselves, the temple complexes attached to them show great mastery of architectural forms. Khufu's temple or approach causeway was decorated with impressive reliefs, fragments of which were incorporated in the 12th-dynasty pyramid of Amenemhet I at al-Lisht. The best known of all Egyptian sculpture, Khafre's Great Sphinx at Giza and his extraordinary seated statue of Nubian gneiss, date from the middle 4th dynasty.

The Giza pyramids form a group of more or less completed monuments surrounded by many tombs of the royal family and the elite, hierarchically organized and laid out in neat patterns. This arrangement contrasts with that of the reign of Snefru, when important tombs were built at Maydūm and Ṣaqqārah, while the King was probably buried at Dahshūr. Of the Giza tombs, only those of the highest-ranking officials were decorated: except among the immediate entourage of the kings, the freedom of expression of officials was greatly restricted. Most of the highest officials were members of the very large royal family, so that power was concentrated by kinship as well as other means. This did not prevent factional strife: the complex of Redjedef was deliberately and thoroughly destroyed, probably at the instigation of his successor, Khafre.

Egyptian expansion into Nubia

The Palermo Stone records a campaign to Lower Nubia in the reign of Snefru that may be associated with graffiti in the area itself. The Egyptians founded a settlement at Buhen, at the north end of the Second Cataract, which endured for 200 years; others may have been founded between there and Elephantine. The purposes of this penetration were probably to establish trade farther south and to create a buffer zone. No archaeological traces of a settled population in Lower Nubia have been found for the Old Kingdom period: the oppressive presence of Egypt seems to have robbed the inhabitants of their resources, rather as the Egyptian provinces were exploited in favour of the king and the elite.

Snefru and the builders of the Giza pyramids represented a classic age to later times. Snefru was the prototype of a good king, whereas Khufu and Khafre had tyrannical reputations, perhaps only because of the size of their monuments. Little direct evidence for political or other attitudes survives from the dynasty, in part because writing was only just beginning to be used for recording continuous texts. Many great works of art were, however, produced for kings and members of the elite, and these set a pattern for later work. Kings of the 4th dynasty identified themselves, at least from the time of Redjedef, as Son of Re (the sun god); worship of the sun god reached a peak in the 5th dynasty.

The 5th dynasty (c. 2465–c. 2325 BC). The first two kings of the 5th dynasty, Userkaf and Sahure, were sons of a lady, Khentkaues, who was a member of the 4th-dynasty royal family. The third king, Neferirkare, may also have been her son. A story from the Middle Kingdom that makes them all sons of a priest of Re may derive from a tradition that they were true worshipers of the sun god and implies, probably falsely, that the 4th-dynasty kings were not. Six kings of the 5th dynasty displayed their devotion to the sun god by building personal temples to his cult. These temples, of which the two so far identified are sited similarly to pyramids, probably had a mortuary significance for the king as well as honouring the god. The kings' pyramids should therefore be seen in conjunction with the temples, some of which received lavish endowments and were served by many high-ranking officials.

Pyramids have been identified for seven of the nine kings of the dynasty, at Ṣaqqārah (Userkaf and Unas, the last king), Abū Ṣīr (Sahure, Neferirkare, Reneferef, and Nuserre), and south Ṣaqqārah (Djedkare Izezi, the eighth king). The pyramids are smaller and less solidly constructed than those of the 4th dynasty, but the reliefs from their mortuary temples are better preserved and of very fine quality; that of Sahure gives a fair impression of their decorative program. The interiors contained religious scenes relating to provision for Sahure in the next life, while the exteriors presented his "historical" role and relations with the gods. Sea expeditions to Lebanon to acquire timber are depicted, as are aggression against and capture of Libyans. Despite their apparent precision, in which captives are named and total figures given, these scenes may not refer to specific events, for the same motifs with the same details were frequently shown over the next 250 years; Sahure's use of them might not have been the earliest.

Relations with foreign lands

Foreign connections were far-flung. Goldwork of the period has been found in Anatolia, while stone vases named for Khafre and Pepi I (6th dynasty) have been found at Tall Mardīkh in Syria, the capital of the important state of Ebla, which was destroyed around 2250 BC. The absence of 5th-dynasty evidence from the site is probably a matter of chance. Expeditions to the turquoise mines of Sinai continued as before. In Nubia, graffiti and inscribed seals from Buhen document Egyptian presence until late in the dynasty, when control was probably abandoned in the face of immigration from the south and the deserts; later generations of the immigrants are known as the Nubian C Group. From the reign of Sahure on, there are records of trade with Punt, a partly legendary land probably in the region of Eritrea, from which the Egyptians obtained incense and myrrh, as well as exotic African products that had been traded from still farther afield. Thus the reduced level of royal display in Egypt does not imply a less prominent general role for the country.

Organization of the country's administration

High officials of the 5th dynasty were no longer members of the royal family, although a few married princesses. Their offices still depended on the king, and in their biographical inscriptions they presented their exploits as relating to him, but they justified other aspects of their social role in terms of a more general morality. They progressed through their careers by acquiring titles in complex ranked sequences that were manipulated by kings throughout the 5th and 6th dynasties. This institutionalization of officialdom has an archaeological parallel in the distribution of elite tombs, which no longer clustered so closely around pyramids. Many are at Giza, but the largest and finest are at Ṣaqqārah and Abū Ṣīr. The repertory of decorated scenes in them continually expanded, but there was no fundamental change in their subject matter. Toward the end of the 5th dynasty some officials with strong local ties began to build their tombs in the Nile Valley and the Delta, in a development that symbolized the elite's slowly growing independence from royal control.

Something of the working of the central administration is visible in papyri from the mortuary temples of Neferirkare and Reneferef at Abū Ṣīr. These show well-developed methods of accounting and meticulous recordkeeping and document the complicated redistribution of goods and materials between the royal residence, the temples, and officials who held priesthoods. Despite this evidence for detailed organization, the consumption of papyrus was modest and cannot be compared, for example, with that of Greco-Roman times.

The last three kings of the dynasty, Menkauhor, Djedkare Izezi, and Unas, did not have personal names compounded with "-Re," the name of the sun god (Djedkare is a name assumed on accession); and Izezi and Unas did not build solar temples. Thus there was a slight shift away from the solar cult. The shift could be linked with the rise

of Osiris, the god of the dead, who is first attested from the reign of Neuserre. His origin was, however, probably some centuries earlier. The pyramid of Unas, whose approach causeway was richly decorated with historical and religious scenes, is inscribed inside with spells intended to aid the deceased in the hereafter; varying selections of the spells occur in all later Old Kingdom pyramids. (As a collection they are known as the Pyramid Texts.) Many of the spells were old when they were inscribed; their presence documents the increasing use of writing rather than a change in beliefs. The Pyramid Texts show the importance of Osiris, at least for the king's passage into the next world: it was an undertaking that aroused anxiety and had to be assisted by elaborate rituals and spells.

The 6th dynasty (c. 2325–c. 2150 BC). No marked change can be discerned between the reigns of Unas and Teti, the first king of the 6th dynasty. Around Teti's pyramid in the northern portion of Ṣaqqārah was built a cemetery of large tombs, including those of several viziers. Together with tombs near the pyramid of Unas, this is the latest group of private monuments of the Old Kingdom in the Memphite area.

Information on 6th-dynasty political and external affairs is more abundant because inscriptions of high officials were longer. Whether the circumstances they describe were also typical of less loquacious ages is unknown, but the very existence of such inscriptions is evidence of a tendency to greater independence among officials. One, Weni, who lived from the reign of Teti through those of Pepi I and Merenre, was a special judge in the trial of a conspiracy in the royal household, mounted several campaigns against a region east of Egypt or in southern Palestine, and organized two quarrying expeditions. In the absence of a standing army, the Egyptian force was levied from the provinces by officials from local administrative centres and other settlements; there were also contingents from several southern countries and a tribe of the Eastern Desert.

Trading expeditions in the 6th dynasty

Three biographies of officials from Elephantine record trading expeditions to the south in the reigns of Pepi I and Pepi II. The location of the regions named in them is debated and may have been as far afield as the Butāna, south of the Fifth Cataract. Some of the trade routes ran through the Western Desert, where the Egyptians established an administrative post at Balāṭ in ad-Dākhilah Oasis, some distance west of al-Khārijah Oasis. Egypt no longer controlled Lower Nubia, which was settled by the C Group and formed into political units of gradually increasing size, possibly as far as Karmah, south of the Third Cataract; relations with this state deteriorated into armed conflict in the reign of Pepi II. Karmah was the southern cultural successor of the Nubian A Group and became an urban centre in the late 3rd millennium BC, remaining Egypt's chief southern neighbour for seven centuries. To the north, the Karmah state stretched as far as the Second Cataract and at times farther still. Its southern extent has not been determined, but sites of similar material culture are scattered over vast areas of the central Sudan.

Increase in provincialization

The provincializing tendencies of the late 5th dynasty continued in the 6th, especially during the extremely long reign (up to 94 years) of Pepi II. Increasing numbers of officials resided in the provinces, amassed local offices, and emphasized local concerns, including religious leadership, in their inscriptions. At the capital the size and splendour of the cemeteries decreased, and some tombs of the end of the dynasty were decorated only in their subterranean parts, as if security could not be guaranteed aboveground. The pyramid complex of Pepi II at southern Ṣaqqārah, which was probably completed in the first 30 years of his reign, stands out against this background as the last major monument of the Old Kingdom, comparable with its predecessors in artistic achievement. Three of his queens were buried in small pyramids around his own; these are the only known queens' monuments inscribed with Pyramid Texts.

The 7th and 8th dynasties (c. 2150–30 BC). Pepi II was followed by several ephemeral rulers, who were in turn succeeded by the short-lived 7th dynasty of Manetho's history (from which no king's name is known) and the 8th, one of whose kings, Ibi, built a small pyramid at southern Ṣaqqārah. Several 8th-dynasty kings are known from inscriptions found in the temple of Min at Qift in the south; this suggests that their rule was recognized throughout the country. The instability of the throne is, however, a sign of political decay, and the fiction of centralized rule may have been accepted only because there was no alternative style of government to kingship.

Collapse of the Old Kingdom state

With the end of the 8th dynasty the Old Kingdom state collapsed. About this time there was widespread famine and violence; the consequent rise in the death rate can be seen in sharply increased numbers of burials in cemeteries. The country emerged impoverished and decentralized from this episode, the prime cause of which may have been political failure, environmental disaster, or, more probably, a combination of the two. In this period the desiccation of northeastern Africa reached a peak, producing conditions similar to those of modern times, and a related succession of low inundations may have coincided with the decay of central political authority. These environmental changes are, however, only approximately dated and their relationship with the collapse cannot be proved.

The First Intermediate Period. *The 9th dynasty (c. 2130–2080 BC).* After the end of the 8th dynasty the throne passed to kings from Heracleopolis, who made their native city the capital, although Memphis continued to be important. They were acknowledged throughout the country, but inscriptions of nomarchs (chief officials of nomes) in the south show that the kings' rule was nominal. At Dara, north of Asyūṭ, for example, a local ruler called Khety styled himself king and built a pyramid with a surrounding "courtly" cemetery. At al-Mi'alla, south of Luxor, Ankhtify, the nomarch of the al-Jabalayn region, recorded his annexation of the Idfū nome and extensive raiding in the Theban area. Ankhtify acknowledged an unidentifiable king Neferkare but campaigned with his own troops. Major themes of inscriptions of the period are the nomarch's provision of food supplies for his people in times of famine and his success in promoting irrigation works. Artificial irrigation had probably long been practiced, but exceptional poverty and crop failure made concern with it worth recording. Inscriptions of Nubian mercenaries employed by local rulers in the south indicate how entrenched military action was.

The 10th (c. 2080–c. 1970 BC) and 11th (2081–1938 BC) dynasties. A period of generalized conflict focused on twin dynasties at Thebes and Heracleopolis. The latter, the 10th, probably continued the line of the 9th. The founder of the 9th or 10th dynasty was named Khety and the dynasty as a whole was termed the House of Khety. Several Heracleopolitan kings were named Khety; another important name is Merikare. Whereas the Theban dynasty was stable, kings succeeded one another rapidly at Heracleopolis. There was continual conflict, and the boundary between the two realms shifted around the region of Abydos. As yet, the course of events in this period cannot be reconstructed.

Several major literary texts purport to describe the upheavals of the First Intermediate Period, the "Instruction for Merikare," for example, being ascribed to one of the kings of the 9th or 10th dynasty. These texts led earlier Egyptologists to posit a Heracleopolitan literary flowering, but there is now a tendency to date them to the Middle Kingdom, so that they would have been written with enough hindsight to allow a more effective critique of the sacred order. The "Heracleopolitan Age" may therefore be a fiction.

Until the 11th dynasty made Thebes its capital, Hermonthis (modern Armant), on the west bank of the Nile, had been the centre of the Theban nome. The dynasty honoured as its ancestor the God's Father Mentuhotep, probably the father of its first king, Inyotef I (2081–65 BC), whose successors were Inyotef II and Inyotef III (2065–16 and 2016–08 BC, respectively). The fourth king, Mentuhotep I (sometimes numbered II; 2008–1957 BC, whose throne name was Nebhepetre), gradually reunited Egypt and ousted the Heracleopolitans, changing his titulary in stages to record his conquests. Around his 20th regnal year he assumed the Horus name Divine of the White Crown,

implicitly claiming all of Upper Egypt. By his regnal year 42 this was changed to Uniter of the Two Lands, a traditional royal epithet that he revived with a literal meaning and presented in a new, emphatic iconography. In later times Mentuhotep was celebrated as the founder of the epoch now known as the Middle Kingdom. His remarkable mortuary complex at Dayr al-Baḥrī, which seems to have had no pyramid, was the architectural inspiration for Hatshepsut's later structure built alongside.

In the First Intermediate Period, monuments were set up by a slightly larger section of the population and, in the absence of central control, internal dissent and conflicts of authority became visible in public records. Nonroyal individuals took over some of the privileges of royalty, notably identification with Osiris in the hereafter and the use of the Pyramid Texts; these were incorporated into a more extensive corpus inscribed on coffins (and hence termed the Coffin Texts) and continued to be inscribed during the Middle Kingdom. The unified state of the Middle Kingdom did not reject these acquisitions and so had a broader cultural basis than the Old Kingdom.

THE MIDDLE KINGDOM (1938–c. 1600 BC) AND THE SECOND INTERMEDIATE PERIOD (c. 1630–1540 BC)

The Middle Kingdom. Mentuhotep I campaigned in Lower Nubia, where he may have been preceded by the Inyotefs. In Thebes he built a novel and impressive mortuary complex at Dayr al-Baḥrī, which served as inspiration for Hatshepsut's adjacent temple 500 years later. The complex contained some of the earliest known depictions of Amon-Re, the dynastic god of the Middle Kingdom and the New Kingdom. Mentuhotep I was himself deified and worshiped, notably in the Aswān area. In administration, he attempted to break the power of the nomarchs, but his policy was unsuccessful in the longer term.

Mentuhotep I's mortuary complex at Dayr al-Baḥrī

Mentuhotep I's successors, Mentuhotep II (1957–45 BC) and Mentuhotep III (1945–38 BC) also ruled from Thebes. The reign of Mentuhotep III corresponds to seven years marked "missing" in the Turin Canon, and he may later have been deemed illegitimate. Records of a quarrying expedition to the Wadi Ḥammāmāt (Wādī Rawḍ ʿĀyd) from his second regnal year were inscribed on the order of his vizier Amenemhet, who almost certainly usurped the throne and founded the 12th dynasty. Not all the country welcomed the 11th dynasty, the monuments and self-presentation of which remained local and Theban.

The 12th dynasty (1938–c. 1756 BC). In a text probably circulated as propaganda during the reign of Amenemhet I (1938–08 BC), the time preceding his reign is depicted as a period of chaos and despair, from which a saviour called Ameny from the extreme south was to emerge. This presentation may well be stereotyped, but there could have been armed struggle before he seized the throne. Nonetheless, his mortuary complex at al-Lisht contained monuments on which his name was associated with that of his predecessor. In style, his pyramid and mortuary temple looked back to Pepi II of the end of the Old Kingdom, but the pyramid was built of mud brick with a stone casing and consequently is badly ruined.

Amenemhet I moved the capital back to the Memphite area, founding a residence named Itj-towy "[Amenemhet is] he who takes possession of the Two Lands," which was for later times the archetypal royal residence. Itj-towy was probably situated between Memphis and the pyramids of Amenemhet I and Sesostris I (at modern al-Lisht), while Memphis remained the centre of population. From later in the dynasty there is the earliest evidence for a royal palace (not a capital) in the eastern Delta. The return to the Memphite area was accompanied by a revival of Old Kingdom artistic styles, in a resumption of central traditions that contrasted with the local ones of the 11th dynasty. In his policy toward the nomarchs, Amenemhet retreated from the absolutism of the Mentuhoteps, and major tombs of the first half of the dynasty, which display considerable local independence, are preserved at several sites, notably Beni Hasan, Mayr, and Qau. After the second reign of the dynasty, no more important private tombs were constructed at Thebes, but several kings made benefactions to Theban temples.

In his 20th regnal year, Amenemhet I took his son Sesostris I (or Senwosret, 1918–1875 BC) as his co-regent, presumably in order to avoid the instability of the First Intermediate Period and its aftermath. This practice was followed in the next two reigns and recurred sporadically in later times. During the following 10 years of joint rule Sesostris undertook campaigns in Lower Nubia that led to its conquest as far as the central area of the Second Cataract. A series of fortresses was begun in the region and there was a full occupation, but the local C Group population was not integrated culturally with the conquerors.

Sesostris I's campaigns to the south

Amenemhet I apparently was murdered during Sesostris' absence on a campaign to Libya, but Sesostris was able to maintain his hold on the throne without major disorder. He consolidated his father's achievements, but, in one of the earliest preserved inscriptions recounting royal exploits, he spoke of internal unrest. An inscription of the next reign alludes to campaigns to Syria-Palestine in the time of Sesostris; whether these were raiding expeditions and parades of strength, in what was then a seminomadic region, or whether a conquest was intended or achieved, is not known. It is clear, however, that the traditional view that the Middle Kingdom hardly intervened in the Near East is incorrect.

In the early 12th dynasty the written language was regularized in its classical form of Middle Egyptian, a rather artificial idiom that was probably always somewhat removed from the vernacular. The first datable corpus of literary texts was composed in Middle Egyptian. Two of these relate directly to political affairs and offer fictional justifications for the rule of Amenemhet I and Sesostris I, respectively. Several that are ascribed to Old Kingdom authors or that describe events of the First Intermediate Period, but are composed in Middle Egyptian, probably also date from around this time. The most significant of these is the "Instruction for Merikare," a discourse on kingship and moral responsibility. It is often used as a source for the history of the First Intermediate Period but may preserve no more than a memory of its events. Most of these texts continued to be copied in the New Kingdom.

Little is known of the reigns of Amenemhet II (1876–42 BC) and Sesostris II (1844–37 BC). These kings built their pyramids in the Fayyūm, while also beginning an intensive exploitation of its agricultural potential that reached a peak in the reign of Amenemhet III (1818–1770 BC). The king of the 12th dynasty with the most enduring reputation was Sesostris III (1836–18 BC), who extended Egyptian conquests to Semna, at the south end of the Second Cataract, while also mounting at least one campaign to Palestine. Sesostris III completed an extensive chain of fortresses in the Second Cataract; at Semna he was worshiped as a god in the New Kingdom.

Frequent campaigns and military occupation, which lasted another 150 years, required a standing army. A force of this type may have been created early in the 12th dynasty but becomes better attested near the end. It was based on "soldiers," whose title means literally "citizens," levied by district, and officers of several grades and types. It was separate from New Kingdom military organization and seems not to have enjoyed very high status.

Egypt's standing army

The purpose of the occupation of Lower Nubia is disputed, because the size of the fortresses and the level of manpower needed to occupy them might seem disproportionate to local threats. An inscription of Sesostris III set up in the fortresses emphasizes the weakness of the Nubian enemy, while a boundary marker and fragmentary papyri show that the system channeled trade with the south through the central fortress of Mirgissa. The greatest period of the Karmah state to the south was still to come, but for centuries it had probably controlled a vast stretch of territory. The best explanation of the Egyptian presence is that Lower Nubia was annexed by Egypt whenever possible, while Karmah was a rival worth respecting and preempting; in addition, the physical scale of the fortresses may have become something of an end in itself. It is not known whether Egypt wished similarly to conquer Palestine, but an inscription of Sesostris' reign records a campaign in Palestine, and numerous administrative seals of the period have been found there.

Sesostris III's administrative reorganization

Sesostris III finally broke the power of the nomarchs and reorganized Egypt into four regions corresponding to the northern and southern halves of the Nile Valley and the eastern and western Delta. Rich evidence for middle-ranking officials from the religious centre of Abydos, and for administrative practice in documents from al-Lahūn, conveys an impression of a pervasive, centralized bureaucracy, which later came to run the country under its own momentum. The prosperity created by peace, conquests, and agricultural development is visible in royal monuments and monuments belonging to the minor elite, but there was no small, powerful, and wealthy group of the sort seen in the Old and New Kingdoms. Sesostris III and his successor, Amenemhet III (1818–*c.* 1770 BC), left a striking artistic legacy in the form of statuary depicting them as aging, careworn rulers, probably alluding to a conception of the suffering king known from literature of the dynasty. This departure from the bland ideal, which may have sought to bridge the gap between king and subjects in the aftermath of the attack on elite power, was not taken up in later times.

The reigns of Amenemhet III and Amenemhet IV (*c.* 1770–1760 BC) and Sebeknefru (*c.* 1760–1756 BC), the first certainly attested female monarch, were apparently peaceful, but the accession of a woman marked the end of the dynastic line.

The 13th dynasty (c. 1756–c. 1630 BC). Despite a continuity of outward forms and of the rhetoric of inscriptions between the 12th and 13th dynasties, there was a complete change in kingship. In little more than a century about 70 kings occupied the throne. Many can have reigned only for months, and there were probably rival claimants to the throne, but in principle the royal residence remained at Itj-towy and the kings ruled the whole country. Egypt's hold on Lower Nubia was maintained, as was its position as the leading state in the Near East. Large numbers of private monuments document the prosperity of the official classes, and a proliferation of titles is evidence of their continued expansion. In government the vizier assumed prime importance, and a single family held the office for much of a century.

Waves of immigration

Asiatic immigration is known in the late 12th dynasty and became widespread in the 13th. From the late 18th century BC the northeastern Delta was settled by successive waves of Palestinians, who retained their own material culture. Starting with the "Instruction for Merikare," Egyptian texts warn against the dangers of infiltration of this sort, and its occurrence shows a weakening of government. There may also have been a rival dynasty, called the 14th, at Xois in the north central Delta, but this is known only from Manetho's history and could have had no more than local significance. Several late 13th-dynasty kings are attested only at Thebes and may have formed a rival line or moved their residence there from the north. Toward the end of this period Egypt lost control of Lower Nubia, where the garrisons, which had been regularly replaced with fresh troops, settled and were partly assimilated. The Karmah state overran and incorporated the region. Some Egyptian officials resident in the Second Cataract area served the new rulers. The site of Karmah has yielded many Egyptian artifacts, including old pieces pillaged from their original contexts. Most were items of trade between the two countries, some probably destined for exchange against goods imported from sub-Saharan Africa. Around the end of the Middle Kingdom and during the Second Intermediate Period, Medjay tribesmen from the Eastern Desert settled in the Nile Valley from around Memphis to the Third Cataract. Their presence is marked by distinctive shallow graves with black-topped pottery, and they have traditionally been termed the "Pan-grave" culture by archaeologists. They were assimilated culturally in the New Kingdom, but the word Medjay came to mean police or militia; they probably came as mercenaries.

The Second Intermediate Period. The increasing competition for power in Egypt and Nubia crystallized in the formation of two new dynasties: the 15th, called the Hyksos (*c.* 1630–*c.* 1523 BC), with its capital at Avaris (Tall ad-Dab'a) in the Delta, and the 17th (*c.* 1630–1540 BC), ruling from Thebes. The word Hyksos goes back to an Egyptian phrase meaning "ruler of foreign lands" and occurs in Manetho's narrative cited in the works of the Jewish historian Josephus (1st century AD), which depicts the new rulers as sacrilegious invaders who despoiled the land. They may have invaded, but they presented themselves—with the exception of the title Hyksos—as Egyptian kings and appear to have been accepted as such. The main line of Hyksos was acknowledged throughout Egypt and may have been recognized as overlords in Palestine, but they tolerated other lines of kings, both those of the 17th dynasty and the various minor Hyksos who are termed the 16th dynasty. The 17th dynasty therefore had to accept that it was a junior line, and in this distinction of status lay an occasion, if not a cause, of later conflict. The 15th dynasty consisted of six kings, the best known being the fifth, Apopis, who reigned for up to 40 years. There were many 17th-dynasty kings, probably belonging to several different families. The northern frontier of the Theban domain was at al-Qusiyya, but there was trade across the border and the Thebans pastured their herds in the Delta.

Rule of the Hyksos

Asiatic rule brought many technical innovations to Egypt, as well as cultural innovations such as new musical instruments and musical styles. The changes affected techniques from bronze working and pottery to looms; and new breeds of animals and new crops were introduced. In warfare, composite bows, new types of daggers and scimitars, and above all the horse and chariot transformed previous practice, although the chariot may ultimately have been as important as a prestige vehicle as for tactical advantages it conferred. The effect of these changes was to bring Egypt, which had been technologically backward, onto the level of western Asia. Because of these advances and the perspectives it opened up, Hyksos rule was decisive for Egypt's later empire in the Near East.

Whereas the 13th dynasty was fairly prosperous, the Second Intermediate Period may have been impoverished. The regional centre of the cult of Osiris at Abydos, which has produced the largest quantity of Middle Kingdom monuments, lost importance, but sites such as Thebes, Idfū, and Kawm al-Aḥmar have yielded significant, if sometimes crudely worked, remains. Virtually no information has come from the north, where the Hyksos ruled, and it is impossible to assess their impact on the economy or on high culture. The Second Intermediate Period was the consequence of political fragmentation and immigration and was not associated with the severe economic collapse of the early First Intermediate Period.

Kamose's challenge of the Hyksos

Toward the end of the 17th dynasty (*c.* 1545 BC), the Theban king Seqenenre challenged Apopis, probably dying in battle against him. Seqenenre's successor, Kamose, renewed the challenge, stating in an inscription that it was intolerable to share his land with an Asiatic and a Nubian (the Karmah ruler). By the end of his third regnal year he had made raids as far south as the Second Cataract (and possibly much farther) and in the north to the neighbourhood of Avaris, also intercepting in the Western Desert a letter sent from Apopis to a new Karmah ruler on his accession. By campaigning to the north and to the south Kamose acted out his implicit claim to the territory ruled by Egypt in the Middle Kingdom. His exploits formed a vital stage in the long struggle to expel the Hyksos.

(J.R.Ba.)

THE NEW KINGDOM

The 18th dynasty. *Ahmose.* Although Ahmose (ruled *c.* 1539–14 BC) had been preceded by Kamose, who was either his father or brother, Egyptian tradition regarded Ahmose as the founder of a new dynasty because he was the native ruler who reunified Egypt. Continuing a recently inaugurated practice, he married his full sister Ahmose-Nofretari. The queen was given the title of God's Wife of Amon. Like her predecessors of the 17th dynasty, Queen Ahmose-Nofretari was influential and highly honoured. A measure of her importance was her posthumous veneration at Thebes, where later pharaohs were depicted offering to her as a goddess among the gods.

Ahmose was very young at his accession, and his campaigns to expel the Hyksos from the Delta and regain former Egyptian territory to the south probably started around

his 10th regnal year. Destroying the Hyksos stronghold at Avaris, in the eastern Delta, he finally drove them beyond the eastern frontier and then besieged Sharuhen (Tall al-Far'ah) in southern Palestine; the full extent of his conquests may have been much greater. His penetration of the Near East came at a time when there was no major established power in the region. This political gap facilitated the creation of an Egyptian "empire."

Ahmose's officers and soldiers were rewarded with spoil and captives, who became personal slaves. This marked the creation of an influential military class. Like Kamose, Ahmose campaigned as far south as Buhen. For the administration of the regained territory he created a new office, overseer of southern foreign lands, which ranked second only to the vizier. Its incumbent was accorded the honorific title of king's son, indicating that he was directly responsible to the king as deputy.

Administration

The early New Kingdom bureaucracy was modeled after that of the Middle Kingdom. The vizier was the chief administrator and the highest judge of the realm. By the middle of the 15th century BC the office had been divided into two, one vizier for Upper and one for Lower Egypt. During the 18th dynasty some young bureaucrats were educated in temple schools, reinforcing the integration of civil and priestly sectors. Early in the dynasty many administrative posts were inherited, but royal appointment of capable officials, often selected from military officers who had served the king on his campaigns, later became the rule. The trend was thus away from bureaucratic families and the inheritance of office.

Amenhotep I. Ahmose's son and successor, Amenhotep I (ruled *c.* 1514–1493 BC), pushed the Egyptian frontier southward to the Third Cataract, near the capital of the Karmah state, while also gathering tribute from his Asiatic possessions and perhaps campaigning in Syria. The emerging kingdom of Mitanni in northern Syria, which is first mentioned on a stela of one of Amenhotep's soldiers and was also known by the name of Nahrin, may have threatened Egypt's conquests to the north.

The New Kingdom saw increased devotion to the state god Amon-Re, whose cult gave the king, as his representative, the mission of expanding Egypt's frontiers. Amon-Re benefited as Egypt was enriched by the spoils of war. Riches were turned over to the god's treasuries, and the king had sacred monuments constructed at Thebes. Under Amenhotep I the pyramidal form of royal tomb was abandoned in favour of a rock-cut tomb, and, except for Akhenaton, all subsequent New Kingdom rulers were buried in concealed tombs in the famous Valley of the Kings in western Thebes. Separated from the tombs, royal mortuary temples were erected at the edge of the desert. Perhaps because of this innovation, Amenhotep I later became the patron deity of the workmen who excavated and decorated the royal tombs. The location of his own tomb is unknown.

Thutmose I and Thutmose II. Lacking a surviving heir, Amenhotep I was succeeded by one of his generals, Thutmose I (ruled 1493–*c.* 1482 BC), who married his own full sister Ahmose. In the south Thutmose destroyed the Karmah state. He inscribed a rock as a boundary marker, later confirmed by Thutmose III, near Kanisa-Kurgus, north of the Fifth Cataract. He then executed a brilliant campaign into Syria and across the Euphrates, where he erected a victory stela near Carchemish.

Thus in the reign of Thutmose I, Egyptian conquests in the Near East and Africa reached their greatest extent, but they may not yet have been firmly held. His little-known successor, Thutmose II (*c.* 1482–79 BC), continued his policies.

Hatshepsut and Thutmose III. At Thutmose II's death his queen and sister, Hatshepsut, had only a young daughter; but a minor wife had borne him a boy, who served as a priest in the Temple of Amon. This son, Thutmose III (ruled 1479–26 BC), later reconquered Egypt's Asiatic empire and became an outstanding ruler. During his first few regnal years Thutmose III theoretically controlled the land, but Hatshepsut governed as regent. Sometime between Thutmose III's second and seventh regnal years she assumed the kingship herself. According to one version of the event, the oracle of Amon proclaimed her king at Karnak, where she was crowned. A more propagandistic account, preserved in texts and reliefs of her splendid mortuary temple at Dayr al-Bahri, ignores the reign of Thutmose II and asserts that her father, Thutmose I, proclaimed her as his successor. Upon becoming king, Hatshepsut became the dominant partner in a joint rule that lasted until her death in about 1458 BC; there are monuments dedicated by Hatshepsut that depict both kings. She had the support of various powerful personalities, who did not, however, form a homogeneous faction; the most notable among them was Senenmut, the steward and tutor of her daughter Neferure. In styling herself king, Hatshepsut adopted the royal titulary but avoided the epithet "mighty bull," regularly employed by other kings. Although in her reliefs she was depicted as a male, pronominal references in the texts generally reflect her womanhood. Similarly, much of her statuary shows her in male form, but there are rarer examples that render her as a woman. In less formal documents she was referred to as "King's Great Wife," that is, "Queen," while Thutmose III was "King." There is thus a certain ambiguity in the treatment of Hatshepsut as king.

Hatshepsut's assumption of the kingship

Her temple reliefs depict pacific enterprises, such as the transporting of obelisks for Amon's temple and a commercial expedition to Punt; her art style looked back to Middle Kingdom ideals. Some warlike scenes are depicted, however, and she may have waged a campaign in Nubia. In one inscription she blamed the Hyksos for the supposedly poor state of the land before her rule, even though they had been expelled from the region more than a generation earlier.

During Hatshepsut's ascendancy Egypt's position in Asia deteriorated because of the expansion of Mitannian power in Syria. Shortly after her death, the Prince of Kadesh, a Syrian city, stood with troops of 330 princes of a Syro-Palestinian coalition at Megiddo; such a force was more than merely defensive and the intention may have been to advance against Egypt. The 330 must have represented all the places of any size in the region that were not subject to Egyptian rule and may be a schematic figure derived from a list of place-names. It is noteworthy that Mitanni itself was not directly involved.

Thutmose III proceeded to Gaza with his army and then to Yehem, subjugating rebellious Palestinian towns along the way. His annals relate how, at a consultation concerning the best route over the Mount Carmel ridge, the King overruled his officers and selected a shorter but more dangerous route through the 'Arūnah Pass and then led the troops himself. The march went smoothly, and when the Egyptians attacked at dawn they prevailed over the enemy troops and besieged Megiddo.

Thutmose III meanwhile coordinated the landing of other army divisions on the Syro-Palestinian littoral, whence they proceeded inland, so that the strategy resembled a pincer technique. The siege ended in a treaty by which Syrian princes swore an oath of submission to the King. As was normal in ancient diplomacy and in Egyptian practice, the oath was binding only upon those who swore it, not upon future generations.

By the end of the first campaign Egyptian domination extended northward to a line linking Byblos and Damascus. Although the Prince of Kadesh remained to be vanquished, Assyria sent lapis lazuli as tribute; Asiatic princes surrendered their weapons, including a large number of horses and chariots. Thutmose III took only a limited number of captives. He appointed Asiatic princes to govern the towns and took their brothers and sons to Egypt, where they were educated at the court. Most eventually returned home to serve as loyal vassals, though some remained in Egypt at court. In order to ensure the loyalty of Asiatic city-states, Egypt maintained garrisons that could quell insurrection and supervise the delivery of tribute. There never was an elaborate Egyptian imperial administration in Asia.

Thutmose III conducted numerous subsequent campaigns in Asia. The submission of Kadesh was finally achieved, but Thutmose III's ultimate aim was the defeat of Mitanni. He used the navy to transport troops to

Asiatic coastal towns, avoiding arduous overland marches from Egypt. His great eighth campaign led him across the Euphrates; although the countryside around Carchemish was ravaged, the city was not taken, and the Mitannian prince was able to flee. The psychological gain of this campaign was perhaps greater than its military success, for Babylonia, Assyria, and the Hittites all sent tribute in recognition of Egyptian dominance. Although Thutmose III never subjugated Mitanni, he placed Egypt's conquests on a firm footing by constant campaigning that contrasts with the forays of his predecessors. His annals inscribed in the temple of Karnak are remarkably succinct and accurate, but his other texts, notably one set up in his newly founded Nubian capital of Napata, are more conventional in their rhetoric.

Thutmose III initiated a truly imperial Egyptian rule in Nubia. Much of the land became estates of institutions in Egypt, while local cultural traits disappear from the archaeological record. Sons of chiefs were educated at the Egyptian court; a few returned to Nubia to serve as administrators—and some were buried there in Egyptian fashion. Nubian fortresses lost their strategic value and became administrative centres. Open towns developed around them, and in several temples outside their walls the cult of the divine king was established. Lower Nubia supplied gold from the desert and hard and semiprecious stones. From farther south came African woods, perfumes, oil, ivory, panther skins, and ostrich plumes. There is scarcely any trace of local population from the later New Kingdom, when many more temples were built in Nubia; by the end of the 20th dynasty the region had almost no prosperous settled population.

Under Thutmose III the wealth of empire became apparent in Egypt. Many temples were built and vast sums were donated to the estate of Amon-Re. There are many tombs of his high officials at Thebes. The capital had been moved to Memphis, but Thebes remained the religious centre.

The campaigns of kings like Thutmose III required a large military establishment, including a hierarchy of officers and a very expensive chariotry. The king grew up with military companions whose close connection with him enabled them to participate increasingly in government. Military officers were appointed to high civil and religious positions, and by the Ramesside period the influence of such people came to outweigh that of the traditional bureaucracy.

Amenhotep II. About two years before his death Thutmose III appointed his 18-year-old son, Amenhotep II (ruled *c.* 1426–1400 BC), as co-regent. Just prior to his father's death, Amenhotep II set out on a campaign to an area near Kadesh, in Syria, whose city-states were now caught up in the power struggle between Egypt and Mitanni; Amenhotep II killed seven princes and shipped their bodies back to Egypt to be suspended from the ramparts of Thebes and Napata. In his seventh and ninth years Amenhotep II made further campaigns into Asia, where the Mitannian king pursued a more vigorous policy. The revolt of the important coastal city of Ugarit was a serious matter, because Egyptian control over Syria required bases along the littoral for inland operations and the provisioning of the army. Ugarit was pacified, and the fealty of Syrian cities, including Kadesh, was reconfirmed.

Amenhotep II's campaigns into Asia

Thutmose IV. Amenhotep II's son Thutmose IV (ruled 1400–1390 BC) sought to establish peaceful relations with the Mitannian king Artatama, who had been successful against the Hittites. Artatama gave his daughter in marriage, the prerequisite for which was probably the Egyptian cession of some Syrian city-states to the Mitannian sphere of influence. This was the first such diplomatic marriage, paving the way for the age of Amenhotep III, when the emphasis shifted from war to diplomacy and the enjoyment of the luxury of empire.

Foreign influences during the early 18th dynasty. During the empire period Egypt maintained commercial ties with Phoenicia, Crete, and the Aegean islands. The Egyptians portrayed goods obtained through trade as foreign tribute. In the Theban tombs there are representations of Syrians bearing Aegean products and of Aegeans carrying Syrian bowls and amphorae—indicative of close commercial interconnections among Mediterranean lands. Egyptian ships trading with Phoenicia and Syria journeyed beyond to Crete and the Aegean, a route that explains the occasional confusion of products and ethnic types in Egyptian representations. The most prized raw material from the Aegean world was silver, which was lacking in Egypt, where gold was relatively abundant.

One result of empire was a new appreciation of foreign culture. Not only were foreign objets d'art imported into Egypt but Egyptian artisans imitated Aegean wares as well. Imported textiles inspired the ceiling patterns of Theban tomb chapels, and Aegean art with its spiral motifs and rendition of movement influenced Egyptian artists. Under Amenhotep II, Asiatic gods are found in Egypt: Astarte and Resheph became revered for their reputed potency in warfare, and Astarte was honoured also in connection with medicine, love, and fertility. Some Asiatic gods were eventually identified with similar Egyptian deities; thus, Astarte was associated with Sekhmet, the goddess of pestilence, and Resheph with Mont, the war god. Just as Asiatics resident in Egypt were incorporated into Egyptian society and could rise to important positions, so their gods, though represented as foreign, were worshiped according to Egyptian cult practices. The breakdown of Egyptian isolationism and increased cosmopolitanism in religion are also reflected in hymns that praise Amon-Re's concern for the welfare of Asiatics.

Amenhotep III. Thutmose IV's son Amenhotep III (ruled 1390–53 BC) acceded to the throne at about the age of 12. He soon wed Tiy, who became his queen. Earlier in the dynasty military men had served as royal tutors; but Tiy's father was a commander of the chariotry, and through this link the royal line became even more directly influenced by the military. In his fifth year Amenhotep III claimed a victory over Cushite rebels, but the Viceroy of Cush, the southern portion of Nubia, probably actually led the troops. The campaign may have led into the Butana, west of the 'Aṭbarah River, farther south than any previous Egyptian military expedition had gone. Several temples erected under Amenhotep III in Upper Nubia between the Second and Third cataracts attest to the importance of the region.

Peaceful relations prevailed with Asia, where control of Egypt's vassals was successfully maintained. A commemorative scarab from the king's 10th year announced the arrival in Egypt of the Mitannian princess Gilukhepa, along with 317 women; thus, another diplomatic marriage helped maintain friendly relations between Egypt and its former foe. Another Mitannian princess was later received into Amenhotep III's harem, and during his final illness the Hurrian goddess Ishtar of Nineveh was sent to his aid. At the expense of older bureaucratic families and the principle of inheritance of office, military men acquired high posts in the civil administration. Most influential was the aged scribe and commander of the elite troops, Amenhotep, son of Hapu, whose reputation as a sage survived into the Ptolemaic period.

Amenhotep III sponsored building on a colossal scale, especially in the Theban area. At Karnak he erected the huge third pylon, and at Luxor he dedicated a magnificent new temple to Amon. The King's own mortuary temple in western Thebes was unrivaled in its size; little remains of it today, but its famous Colossi of Memnon testify to its proportions. He also built a huge harbour and palace complex nearby. Some colossal statues served as objects of public veneration, before which men could appeal to the king's *ka,* which represented the transcendent aspect of kingship. In Karnak, statues of Amenhotep, son of Hapu, were placed to act as intermediaries between supplicants and the gods.

Among the highest-ranking officials at Thebes were men of Lower Egyptian background, who constructed large tombs with highly refined decoration. An eclectic quality is visible in the tombs, certain scenes of which were inspired by Old Kingdom reliefs. The revolutionary art of the succeeding Amarna period perhaps reflects a reaction against the studied perfection of Theban art. The earliest preserved important New Kingdom monuments from Memphis also date from this reign. Antiquarianism is ev-

idenced in Amenhotep III's celebration of his *sed* festivals (rituals of renewal celebrated after 30 years of rule), which were performed at his Theban palace in accordance, it was claimed, with ancient writings. Tiy, whose role was much more prominent than that of earlier queens, participated in these ceremonies.

Amenhotep III's last years were spent in ill health. To judge from his mummy and less formal representations of him from Amarna, he was obese when, in his 38th regnal year, he died and was succeeded by his son Amenhotep IV (ruled 1353–36 BC), the most controversial of all the kings of Egypt.

Amenhotep IV (Akhenaton). The earliest monuments of Amenhotep IV, who in his fifth regnal year changed his name to Akhenaton ("one useful to Aton"), are conventional in their iconography and style, but from the first he gave the sun god a didactic title naming Aton, the solar disk. This title was later written inside a pair of cartouches, as a king's name would be. The king declared his religious allegiance by the unprecedented use of "high priest of the sun god" as one of his own titles. The term Aton had long been in use, but under Thutmose IV the Aton had been referred to as a god, and under Amenhotep III those references became more frequent. Thus, Akhenaton did not create a new god but rather singled out this aspect of the sun god from among others. He also carried further radical tendencies that had recently developed in solar religion, in which the sun god was freed from his traditional mythological context and presented as the sole beneficent provider for the entire world. The King's own divinity was emphasized: the Aton was said to be his father, of whom he alone had knowledge, and they shared the status of king and celebrated jubilees together.

In his first five regnal years, Akhenaton built many temples to the Aton, of which the most important were in the precinct of the temple of Amon-Re at Karnak. In these open-air structures was developed a new, highly stylized form of relief and sculpture in the round. The Aton was depicted not in anthropomorphic form but as a solar disk from which radiating arms extend the hieroglyph for "life" to the noses of the king and his family. During the construction of these temples the cult of Amon and other gods was suspended, and the worship of the Aton in an open-air sanctuary superseded that of Amon, who had dwelt in a dark shrine of the Karnak temple. The King's wife Nefertiti, whom he had married before his accession, was prominent in the reliefs and had a complete shrine dedicated to her that included no images of the King. Her prestige continued to grow for much of the reign.

The transfer of the capital to Amarna

At about the time that he altered his name to conform with the new religion, the King transferred the capital to a virgin site at Amarna (now Tell el-Amarna) in Middle Egypt. There, he constructed a well-planned city—Akhetaton ("The Horizon of Aton")—comprising temples to the Aton, palaces, official buildings, villas for the high ranking, and extensive residential quarters. In the eastern desert cliffs surrounding the city, tombs were excavated for the courtiers; and deep within a secluded wadi the royal sepulchre was prepared. Reliefs in these tombs have been invaluable for reconstructing life at Amarna. The tomb reliefs and stelae portray the life of the royal family with an unprecedented degree of intimacy. They also show that the city was laid out as a great stage, on which the king's daily journeys from palace to city and back made manifest the passage of the sun across the sky.

In Akhenaton's ninth year a more monotheistic didactic name was given to the Aton, and an intense persecution of the older gods, especially Amon, was undertaken. Amon's name was excised from many older monuments throughout the land, and occasionally the word "gods" was expunged. This evidence suggests that the King's monotheistic fervour intensified.

Akhenaton's religious and cultural revolution was highly personal. The peculiar depiction of his physiognomy became the norm for representing not only members of the royal family but commoners as well. In religion the accent was upon the sun's life-sustaining power, and naturalistic scenes adorned the walls and even the floors of Amarna buildings. The king's role in determining the composition of the court is expressed in epithets given to officials he selected from the lesser ranks of society, including the military. Few officials had any connection with the old ruling elite, and some courtiers who had been accepted at the beginning of the reign were purged. Even at Amarna the new religion was not widely accepted below the level of the elite; numerous small objects relating to traditional beliefs have been found at the site.

Akhenaton's revolutionary intent is visible in all of his actions. In representational art, many existing conventions that had no special religious meaning were reversed to emphasize the break with the past. Such a procedure is comprehensible because traditional values were consistently incorporated in cultural expression as a whole; in order to change one part it was necessary to change the whole.

A vital innovation was the introduction of current vernacular forms into the written language. This led in later decades to the creation of new styles for monumental inscriptions and for everyday use. The latter variant, which is now known as Late Egyptian, was not fully developed until the later 19th dynasty.

Akhenaton's violent changes could not have been accomplished without the military, who are ubiquitous in the reliefs, especially from the Karnak temples. Akhenaton's foreign policy and use of force abroad are less well understood. He mounted one minor campaign in Nubia. In the Near East, Egypt's hold on its possessions was not as secure as earlier, but the cuneiform tablets found at Amarna recording his diplomacy are difficult to interpret because the vassals who requested aid from him exaggerated their plight. One reason for unrest in the region was the decline of Mitanni and the resurgence of the Hittites. Between the reign of Akhenaton and the end of the 18th dynasty, Egypt lost control of much territory in Syria.

The aftermath of Amarna. Akhenaton had six daughters by Nefertiti and one or two sons, perhaps by a secondary wife Kiya or by his own daughter Maketaton, who may have died in childbirth and whose infant son is shown in the royal tomb at Amarna. His immediate, ephemeral successor was a woman, possibly his eldest daughter Meritaton. Either she or the widow of Tutankhamen called on the Hittite king Suppiluliumas to supply a consort because she could find none in Egypt; a prince Zannanza was sent, but he was murdered as he reached Egypt. Thus Egypt never had a diplomatic marriage in which a foreign man was received into the country.

Succession of Tutankhaten (Tutankhamen)

After the brief rule of Smenkhkare (1335–32 BC), possibly a son of Akhenaton, Tutankhaten, a nine-year-old child, succeeded and was married to the much older Ankhesenpaaten, Akhenaton's third daughter. Around his third regnal year, the King moved his capital to Memphis, abandoned the Aton cult, and changed his and the Queen's names to Tutankhamen and Ankhesenamen. In an inscription recording Tutankhamen's actions for the gods, the Amarna period is described as one of misery and of the withdrawal of the gods from Egypt. This change, made in the name of the young king, was probably the work of high officials. The most influential were Ay, known by the title God's Father, who served as vizier and regent (his title indicates a close relationship to the royal family), and the general Horemheb, who functioned as royal deputy and whose tomb at Saqqārah contains remarkable scenes of Asiatic captives being presented to the King.

Just as Akhenaton had adapted and transformed the religious thinking that was current in his time, the reaction to the religion of Amarna was influenced by the rejected doctrine. In the new doctrine, all gods were in essence three: Amon, Re, and Ptah (to whom Seth was later added), and in some ultimate sense they too were one. The earliest evidence of this triad is on a trumpet of Tutankhamen and is related to the naming of the three chief army divisions after these gods; religious and secular life were not separate. This concentration on a small number of essential deities may possibly be related to the piety of the succeeding Ramesside period, because both viewed the cosmos as being thoroughly permeated with the divine.

Under Tutankhamen a considerable amount of building was accomplished in Thebes. His Luxor colonnade bears detailed reliefs of the traditional beautiful festival of Opet;

at Karnak he decorated a structure with warlike scenes. He affirmed his legitimacy by referring back to Amenhotep III, whom he called his father. Tutankhamen's modern fame comes from the discovery of his rich burial in the Valley of the Kings. His tomb equipment was superior in quality to the fragments known from other royal burials, and the opulent display—of varying aesthetic value—represents Egyptian wealth at the peak of the country's power.

Ay and Horemheb. Tutankhamen's funeral in about 1323 BC was conducted by his successor, the aged Ay (ruled 1323–19 BC), who in turn was succeeded by Horemheb. The latter probably ruled from 1319 to *c.* 1292 BC, but the length of his poorly attested reign is not certain. Horemheb dismantled many monuments erected by Akhenaton and his successors and used the blocks as fill for huge pylons at Karnak. In this process Nefertiti's image seems to have been defaced more than others. At Karnak and Luxor he appropriated Tutankhamen's reliefs by surcharging the latter's cartouches with his own. Horemheb appointed new officials and priests not from established families but from the army. His policies concentrated on domestic problems. He issued police regulations dealing with the misbehaviour of palace officials and personnel, and he reformed the judicial system, reorganizing the courts and selecting new judges.

The Ramesside period (19th and 20th dynasties). Horemheb was the first post-Amarna king to be considered legitimate in the 19th dynasty, which looked to him as the founder of an epoch. Having no son, he selected his general and vizier, Ramses, to succeed him.

Ramses I and Seti I. Ramses I (ruled 1292–90 BC) hailed from the eastern Delta, and with the 19th dynasty there was a political shift into the Delta. Ramses I was succeeded by his son and co-regent, Seti I, who buried his father and provided him with mortuary buildings at Thebes and Abydos.

Seti I (ruled 1290–79 BC) was a successful military leader who reasserted authority over Egypt's weakened empire in the Near East. The Mitanni state had been dismembered and the Hittites had become the dominant Asiatic power. Before tackling them, Seti laid the groundwork for military operations in Syria by fighting farther south against nomads and Palestinian city-states; then, following the strategy of Thutmose III, he secured the coastal cities and gained Kadesh. Although his engagement with the Hittites was successful, Egypt acquired only temporary control of part of the north Syrian plain. A treaty was concluded with the Hittites who, however, subsequently pushed farther southward and regained Kadesh by the time of Ramses II. Seti I ended a new threat to Egyptain security when he defeated Libyans attempting to enter the Delta. He also mounted a southern campaign, probably to the Fifth Cataract region.

Seti I's reign looked for its model to the mid-18th dynasty and was a time of considerable prosperity. Seti I restored countless monuments that had been defaced in the Amarna period, and the refined decoration of his monuments, particularly his temple at Abydos, shows a classicizing tendency. He also commissioned striking and novel reliefs showing stages of his campaigns, which are preserved notably on the north wall of the great hypostyle hall at Karnak. This diversity of artistic approach is characteristic of the Ramesside period, which was culturally and ethnically pluralistic.

Ramses II. Well before his death, Seti I appointed his son Ramses II, sometimes called Ramses the Great, as crown prince. During the long reign of Ramses II (1279–13 BC) there was a prodigious amount of building, ranging from religious edifices throughout Egypt and Nubia to a new cosmopolitan capital, Pi Ramesse (Tall ad-Dab'a), in the eastern Delta; his cartouches were carved ubiquitously, often on earlier monuments. Ramses II's penchant for decorating vast temple walls with battle scenes gives the impression of a mighty warrior king. His campaigns were, however, relatively few, and after the first decade his reign was peaceful. The most famous scenes record the battle of Kadesh, fought in his fifth regnal year. These and extensive accompanying texts present the battle as an Egyptian victory, but in fact the opposing Hittite coalition fared at least as well as the Egyptians. After this inconclusive struggle, his officers advised him to make peace, saying, "There is no reproach in reconciliation when you make it." In succeeding years Ramses II campaigned in Syria; after a decade of stalemate, a treaty in his 21st year was concluded with Hattusilis III, the Hittite king.

Treaty with the Hittites

The rise of Assyria and unrest in western Anatolia encouraged the Hittites to accept this treaty, while Ramses II may have feared a new Libyan threat to the western Delta. Egyptian and Hittite versions of the treaty survive. It contained a renunciation of further hostilities, a mutual alliance against outside attack and internal rebellion, and the extradition of fugitives. The gods of both lands were invoked as witnesses. The treaty was further cemented 13 years later by Ramses II's marriage to a Hittite princess.

The King had an immense family by his numerous wives, among whom he especially honoured Nefertari. He dedicated a temple to her at Abu Simbel, in Nubia, and built a magnificent tomb for her in the Valley of the Queens.

For the first time in more than a millennium, princes were prominently represented on the monuments. Ramses II's fourth surviving son, Khaemwese, was famous as high priest of Ptah at Memphis. He restored many monuments in the Memphite area, including pyramids and pyramid temples of the Old Kingdom, and had buildings constructed near the Sarapeum at Saqqārah. He was celebrated into Roman times as a sage and magician and became the hero of a cycle of stories.

Merneptah. Ramses II's 13th son, Merneptah (ruled 1213–04 BC), was his successor. Several of Merneptah's inscriptions, of unusual literary style, treat an invasion of the western Delta in his fifth year by Libyans, supported by groups of Sea Peoples who had traveled from Anatolia to Libya in search of new homes. The Egyptians defeated this confederation and settled captives in military camps to serve as Egyptian mercenaries.

One of the inscriptions concludes with a poem of victory (written about another battle), famous for its words, "Israel is desolated and has no seed." This is the earliest documented mention of Israel; it is generally assumed that the exodus of the Jews from Egypt took place under Ramses II.

Merneptah was able to hold most of Egypt's possessions, although early in his reign he had to reassert Egyptian suzerainty in Palestine, destroying Gezer in the process. Peaceful relations with the Hittites and respect for the treaty of Ramses II are indicated by Merneptah's dispatch of grain to them during a famine and by Egyptian military aid in the protection of Hittite possessions in Syria.

Last years of the 19th dynasty. Upon the death of Merneptah, competing factions within the royal family contended for the succession. Merneptah's son Seti II (ruled 1204–1198 BC) had to face a usurper, Amenmeses, who rebelled in Nubia and was accepted in Upper Egypt. His successor, Siptah, was installed on the throne by a Syrian royal butler, Bay, who had become chancellor of Egypt. Siptah was succeeded by Seti II's widow Tausert, who ruled as king from 1193 to 1190 BC, counting her regnal years from the death of Seti II, whose name she restored over that of Siptah. A description in a later papyrus of the end of the dynasty alludes to a Syrian usurper, probably Bay, who subjected the land to harsh taxation and treated the gods as mortals with no offerings in their temples.

The early 20th dynasty: Setnakht and Ramses III. Order was restored by a man of obscure origin, Setnakht (ruled 1190–87 BC), the founder of the 20th dynasty, who appropriated Tausert's tomb in the Valley of the Kings. An inscription of Setnakht recounts his struggle to pacify the land, which ended in the second of his three regnal years.

Setnakht's son Ramses III (ruled 1187–56 BC) was the last great king of the New Kingdom. There are problems in evaluating his achievements because he emulated Ramses II and copied numerous scenes and texts of Ramses II in his mortuary temple at Madīnat Habu, one of the best preserved temples of the empire period. Thus, the historicity of certain Nubian and Syrian wars depicted as his accomplishments is subject to doubt. He did, however, fight battles that were more decisive than any fought by

Ramses II. In his fifth year Ramses III defeated a large-scale Libyan invasion of the Delta in a battle in which thousands of the enemy perished.

A greater menace lay to the north, where a confederation of Sea Peoples was progressing by land and sea toward Egypt. This alliance of obscure tribes came south in the aftermath of the destruction of the Hittite empire. In his eighth regnal year Ramses III engaged them successfully on two frontiers—a land battle in Palestine and a naval engagement in one of the mouths of the Delta. Because of these two victories, Egypt did not undergo the political turmoil or experience the rapid technical advance of the early Iron Age in the Near East. Forced away from the borders of Egypt, the Sea Peoples sailed farther westward, and some of their groups may have given their names to the Sicilians, Sardinians, and Etruscans. The Philistine and Tjekker peoples, who had come by land, were established by the Egyptians in military camps in the southern Palestinian coastal district in an area where the overland trade route to Syria was threatened by attacks by nomads. Initially settled to protect Egyptian interests, these groups later became independent of Egypt. Ramses III used some of these peoples as mercenaries, even in battle against their own kinfolk. In his 11th year he successfully repulsed another great Libyan invasion by the Meshwesh tribes. Meshwesh prisoners of war, branded with the king's name, were settled in military camps in Egypt, and in later centuries their descendants became politically important because of their ethnic cohesiveness and their military role.

These great defensive wars drained the Egyptian economy. Under Ramses III the estate of Amon received only one-fifth as much gold as in Thutmose III's time. Although there are artistic masterpieces at Madīnat Habu, much of the relief inside the temple and the quality of the masonry betray a decline. Toward the end of his reign, administrative inefficiency and the deteriorating economic situation resulted in the government's failure to deliver grain rations on time to necropolis workers, whose dissatisfaction was expressed in demonstrations and in the first recorded strikes in history. Such demonstrations continued sporadically throughout the dynasty. A different sort of internal trouble originated in the royal harem, where a minor queen plotted unsuccessfully to murder Ramses III so that her son might become king. Involved in the plot were palace and harem personnel, government officials, and army officers. A special court of 12 judges was formed to try the accused, who received the death sentence.

Harem conspiracy against Ramses III

Many literary works date to the Ramesside period. Earlier works in Middle Egyptian were copied in schools and in good papyrus copies, and new texts were composed in Late Egyptian. Notable among the latter are stories, several with mythological or allegorical content, that look to folk models rather than to the elaborate written literary types of the Middle Kingdom.

Ramses IV. Ramses III was succeeded by his son Ramses IV (ruled 1156–50 BC). In an act of piety that also reinforced his legitimacy, Ramses IV saw to the compilation of a long papyrus in which the deceased Ramses III confirmed the temple holdings throughout Egypt; Ramses III had provided the largest benefactions to the Theban temples, in terms of donations of both land and personnel. Most of these probably endorsed earlier donations, to which each king added his own gifts. Of the annual income to temples, 86 percent of the silver and 62 percent of the grain was awarded to Amon. The document demonstrates the economic power of the Theban temples, for the tremendous landholdings of Amon's estate throughout Egypt involved the labour of a considerable portion of the population; but the ratio of temple to state income is not known, and the two were not administratively separate. In addition, the temple of Amon, which figures prominently in the papyrus, included within its estates the King's own mortuary temple, for Ramses III was himself deified as a form of Amon-Re, known as Imbued with Eternity.

The later Ramesside kings. The Ramesside period saw a tendency toward the formation of high-priestly families, which kings sometimes tried to counter by appointing outside men to the high priesthood. One such family had developed at Thebes in the second half of the 19th dynasty, and Ramses IV tried to control it by installing Ramessesnakht, the son of a royal steward, as Theban high priest. Ramessesnakht participated in administrative as well as priestly affairs; he personally led an expedition to the Wadi Ḥammāmāt (modern Wādī Rawḍ ʿĀʾid) quarries in the Eastern Desert, and at Thebes he supervised the distribution of rations to the workmen decorating the royal tomb. Under Ramses V (ruled 1150–45 BC), Ramessesnakht's son not only served as steward of Amon but also held the post of administrator of royal lands and chief taxing master. Thus, this family acquired extensive authority over the wealth of Amon and over state finances; but to what extent this threatened royal authority is uncertain. Part of the problem in evaluating the evidence is that Ramesside history is viewed from a Theban bias, because Thebes is the major source of information. Evidence from Lower Egypt, where the king normally resided, is meagre because of unfavourable conditions there for the preservation of monuments or papyri.

Rise in power of high-priestly families

A long papyrus from the reign of Ramses V contains valuable information on the ownership of land and taxation. In Ramesside Egypt most of the land belonged to the state and the temples, while most peasants served as tenant farmers. Some scholars interpret this document as indicating that the state retained its right to tax temple property, at an estimated one-tenth of the crop.

Ramses VI (ruled 1145–37 BC), probably a son of Ramses III, usurped much of his two predecessors' work, including the tomb of Ramses V; a papyrus refers to a possible civil war at Thebes. Following the death of Ramses III the Asiatic empire had rapidly withered away, and Ramses VI is the last king whose name appears at the Sinai turquoise mines. The next two Ramses (ruled 1137–26 BC) were obscure rulers, whose sequence has been questioned. During the reigns of Ramses IX (ruled 1126–08 BC) and Ramses X (1108–04 BC) there are frequent references in the papyri to the disruptions of marauding Libyans near the Theban necropolis.

By the time of Ramses IX the Theban high priest had attained great local influence, though he was still outranked by the king. Early in the reign of Ramses XI (ruled 1104–*c.* 1075 BC), during a civil war at Thebes, the high priest Amenhotep, the son of Ramessesnakht, was suppressed from his office for nine months; the King called upon Panehsy, the viceroy of Cush, to restore order and the fighting spread as far north as Middle Egypt. By Ramses XI's 19th regnal year the Viceroy was driven back and the new high priest of Amon, Herihor—who seems to have had a military background and also claimed the vizierate and the office of Viceroy of Cush—controlled the Theban area. In reliefs at the temple of Khons at Karnak, Herihor was represented as high priest of Amon in scenes adjoining those of Ramses XI. This in itself was unusual, but subsequently he took an even bolder step in having himself depicted as king to the exclusion of the still-reigning Ramses XI. Herihor's kingship was restricted to Thebes, where these years were referred to as a "repeating of [royal] manifestations," which lasted a decade.

With the shrinkage of the empire, the supply of silver and copper was cut off, and the amount of gold entering the economy was reduced considerably. During the reign of Ramses IX the economically distressed inhabitants of western Thebes were found to have pillaged the tombs of kings and nobles (already a common practice in the latter case); the despoiling continued into the reign of Ramses XI, and even the royal mortuary temples were stripped of their valuable furnishings. Nubian troops, called in to restore order at Thebes, themselves contributed to the depredation of monuments. This pillaging brought fresh gold and silver into the economy, and the price of copper rose. The price of grain, which had been inflating, dropped.

Despoiling of tombs

While Ramses XI was still king, Herihor died and was succeeded as high priest by Piankh, a man of similar military background. A series of letters from Thebes tell of Piankh's military venture in Nubia against the former Viceroy of Cush, while Egypt was on the verge of losing control of the south. With the death of Ramses XI, the governor of Tanis, Smendes, became king, founding the 21st dynasty (known as the Tanite).

The Ramesside growth of priestly power was matched by increasingly overt religiosity. Private tombs, the decoration of which had been mostly secular, came to include only religious scenes; oracles were invoked in many kinds of decisions; and private letters contain frequent references to prayer and to regular visits to small temples to perform rituals or consult oracles. The common expression used in letters, "I am all right today; tomorrow is in the hands of god," reflects the ethos of the age. This fatalism, which emphasizes that the god may be capricious and that his wishes cannot be known, is also typical of late New Kingdom Instruction Texts, which show a marked change from their Middle Kingdom forerunners by moving toward a passivity and quietism that suits a less expensive age.

Some of the religious material of the Ramesside period exhibits changes in conventions of display, and some categories have no parallel in the less abundant earlier record, but the shift is real as well as apparent. In its later periods, Egyptian society, the values of which had previously tended to be centralized, secular, and political, became more locally based and more thoroughly pervaded by religion, looking to the temple as the chief institution.

EGYPT FROM 1075 BC TO THE MACEDONIAN INVASION

The Third Intermediate Period (1075–656 BC). *The 21st dynasty.* At the end of the New Kingdom, then, Egypt was divided. The north was inherited by the Tanite 21st dynasty (1075–*c.* 950 BC), and much of the Nile Valley came under the control of the Theban priests (the northern frontier of their domain was the fortress town of al-Hība). Some Theban priests locally assumed the title of king, but there is no indication of conflict between the priests and the Tanite pharaohs. Indeed, the dating of documents, even at Thebes, was in terms of the Tanite reigns, and apparently there were close family ties between the pharaohs and the Thebans. Piankh's son, Pinudjem I, who relinquished the office of high priest and assumed the kingship at Thebes, was probably the father of the Tanite pharaoh Psusennes I. Some members of both the Theban priestly and the Tanite royal lines had Libyan names. With the coming of the new dynasty, and possibly a little earlier, the Meshwesh Libyan military elite, which had been settled mainly in the north by Ramses III, penetrated the ruling group, although it did not become dominant until the 22nd dynasty.

Beginning with Herihor and continuing through the 21st dynasty, the high priests' activities included the pious rewrapping and reburial of New Kingdom royal mummies. The ransacking of the royal tombs during the 20th dynasty necessitated the transfer of the royal remains in stages to two caches—the tomb of Amenhotep II and a cliff tomb at Dayr al-Baḥrī—where they remained undisturbed until modern times. Dockets pertaining to the reburial of these mummies contain important chronological data from the 21st dynasty.

The burials of King Psusennes I (ruled *c.* 1045–*c.* 997 BC) and his successor, Amenemope (ruled *c.* 998–*c.* 989 BC), were discovered at Tanis, but little is known of their reigns. This was a period of the usurpation of statuary and the reuse of material of earlier periods. At Karnak, Pinudjem I, who decorated the facade of the Khons temple, usurped a colossal statue of Ramses II, and Psusennes I's splendid sarcophagus from Tanis had originally been carved for Merneptah. Much of the remains from Tanis comprises material transported from other sites, notably from Pi Ramesse.

After the demise of Egypt's Asiatic empire, the kingdom of Israel eventually developed under the kings David and Solomon. During David's reign, Philistia served as a buffer between Egypt and Israel; but upon David's death the next to the last king of the 21st dynasty, Siamon, invaded Philistia and captured Gezer. If Egypt had any intention of attacking Israel, Solomon's power forestalled Siamon, who presented Gezer to Israel as a dowry in the diplomatic marriage of his daughter to Solomon. This is indicative of the reversal of Egypt's status in foreign affairs since the time of Amenhotep III, who had written the Babylonian king, "From of old, a daughter of the king of Egypt has not been given to anyone."

Siamon's presentation of Gezer to Israel

Libyan rule: the 22nd and 23rd dynasties. The fifth king of the 21st dynasty, Osorkon I (ruled *c.* 979–*c.* 973 BC), was of Libyan descent and probably was an ancestor of the 22nd dynasty, which followed a generation later. From his time to the 26th dynasty, leading Libyans in Egypt kept their Libyan names and ethnic identity, but in a spirit of ethnicity rather than cultural separatism. Although political institutions were different from those of the New Kingdom, the Libyans were culturally Egyptian, retaining only their group identity, names, and perhaps a military ethos. Toward the end of the 21st dynasty the Libyan leader of Bubastis, the great Meshwesh chief Sheshonk I (the biblical Shishak), secured special privileges from King Psusennes II (ruled *c.* 964–*c.* 950 BC) and the oracle of Amon for the mortuary cult of his father at Abydos. The oracle proffered good wishes not only for Sheshonk and his family but, significantly, also for his army. With a strong military backing, Sheshonk eventually took the throne. His reign (*c.* 950–929 BC) marks the founding of the 22nd dynasty (*c.* 950–*c.* 730 BC). Military controls were established, with garrisons under Libyan commandants serving to quell local insurrections, so that the structure of the state became more feudalistic. The dynasty tried to cement relations with Thebes through political marriages with priestly families. King Sheshonk's son Osorkon married Psusennes II's daughter, and their son eventually became high priest at Karnak. By installing their sons as high priests and promoting such marriages, kings strove to overcome the administrative division of the country. But frequent conflicts arose over the direct appointment of the Theban high priest from among the sons of Libyan kings and over the inheritance of the post by men of mixed Theban and Libyan descent. This tension took place against a background of Theban resentment of the northern dynasty. During the reign of Takelot II, strife concerning the high priestship led to civil war at Thebes. The King's son Osorkon was appointed high priest, and he achieved some semblance of order during his visits to Thebes, but he was driven from the post several times.

Renewed influence in Palestine

The initially successful 22nd dynasty revived Egyptian influence in Palestine. After Solomon's death (*c.* 936), Sheshonk I entered Palestine and plundered Jerusalem. Prestige from this exploit may have lasted through the reign of Osorkon II (formerly numbered I; ruled *c.* 929–*c.* 914 BC). In the reign of Osorkon III (ruled *c.* 888–*c.* 860 BC), Peywed Libyans posed a threat to the western Delta, perhaps necessitating a withdrawal from Palestine.

The latter part of the dynasty was marked by fragmentation of the land: Libyan great chiefs ruled numerous local areas, and there were as many as six kings in the land at a time. Increased urbanization accompanied this fragmentation, which was most intense in the Delta. Meanwhile, in Thebes, a separate 23rd dynasty was recognized.

From the 9th century BC a local Cushite state, which looked to Egyptian traditions from the colonial period of the New Kingdom, arose in the Sudan and developed around the old regional capital of Napata. The earliest ruler of the state known by name was Alara, whose piety toward Amon is mentioned in several inscriptions. His successor, Kashta, proceeded into Upper Egypt, forcing Osorkon IV (ruled *c.* 777–*c.* 750 BC) to retire to the Delta. Kashta assumed the title of king and compelled Osorkon IV's daughter Shepenwepe I, the God's Wife of Amon at Thebes, to adopt his own daughter Amonirdis I as her successor. The Cushites stressed the role of the God's Wife of Amon, who was a virgin and the consecrated partner of Amon, and sought to bypass the high priests.

The 24th and 25th dynasties. Meanwhile, the eastern Delta capital, Tanis, lost its importance to Sais in the western Delta. A Libyan prince of Sais, Tefnakhte, attempting to gain control over all Egypt, proceeded southward to Heracleopolis after acquiring Memphis. This advance was met by the Cushite ruler Piye (now the accepted reading of "Piankhi," ruled *c.* 750–*c.* 719 BC), who executed a raid as far north as Memphis and received the submission of the northern rulers (in about 730 BC). In his victory stela, Piye is portrayed as conforming strictly to Egyptian norms and reasserting traditional values against contemporary decay.

Upon Piye's return to Cush, Tefnakhte reasserted his

authority in the north, where he was eventually succeeded by his son Bocchoris, according to Manetho the sole king of the 24th dynasty (*c.* 722–*c.* 715 BC). Piye's brother Shabaka meanwhile founded the rival 25th dynasty and brought all Egypt under his rule (*c.* 719–703 BC). He had Bocchoris burned alive and removed all other claimants to the kingship.

Growth of the Assyrian Empire

In this period Egypt's internal politics were affected by the growth of the Assyrian Empire. In Palestine and Syria frequent revolts against Assyria were aided by Egyptian forces. Against the power of Assyria, the Egyptian and Nubian forces met with little success, partly because of their own fragmented politics and divided loyalties.

Although the earlier years of King Taharqa (ruled 690–664 BC), who as second son of Shabaka had succeeded his brother Shebitku (ruled 703–690 BC), were prosperous, the confrontation with Assyria became acute. In 671 BC the Assyrian king Esarhaddon entered Egypt and drove Taharqa into Upper Egypt. Two years later Taharqa regained a battered Memphis, but in 667 BC Esarhaddon's successor, Ashurbanipal, forced Taharqa to Thebes, where the Cushites held ground. Taharqa's successor, Tanutamon, defeated at Memphis a coalition of Delta princes who supported Assyria, but Ashurbanipal's reaction to this was to humiliate Thebes, which the Assyrians plundered. By 656 the Cushites had withdrawn from the Egyptian political scene, although Cushite culture survived in the Sudanese Napatan and Meroitic kingdom for another millennium.

The Late Period (664–332 BC). *The 26th dynasty (664–525 BC).* Assyria, unable to maintain a large force in Egypt, supported several Delta vassal princes, including the powerful Psamtik I of Sais. But the Assyrians faced serious problems closer to home, and Psamtik (or Psammetichus I, ruled 664–610 BC) was able to assert his independence and extend his authority as king over all Egypt without extensive use of arms, inaugurating the Saite 26th dynasty. In 656 Psamtik I compelled Thebes to submit. He allowed its most powerful man, who was Montemhat, the mayor and the fourth prophet of Amon, to retain his post and, in order to accommodate pro-Cushite sentiments, he allowed the God's Wife of Amon and the Votaress of Amon (the sister and daughter of the late king Taharqa) to remain. Psamtik I's own daughter Nitocris was adopted by the Votaress of Amon and thus became heiress to the position of God's Wife. Essential to the settling of internal conflicts was the Saite dynasty's superior army, composed of Libyan soldiers, whom the Greeks called Machimoi (warriors), and Greek and Carian mercenaries, who formed part of the great emigration from the Aegean in the 7th and 6th centuries BC. Greek pirates raiding the Delta coast were induced by Psamtik I to serve in his army and were settled like the Machimoi in colonies at the Delta's strategically important northeastern border. Trade developed between Egypt and Greece, and more Greeks settled in Egypt.

Foreign policy under the Saites

The Saite dynasty generally pursued a foreign policy that avoided territorial expansion and tried to preserve the status quo. Assyria's power was waning. In 655 BC Psamtik I marched into Philistia in pursuit of the Assyrians, and in 620 BC he apparently repulsed Scythians from the Egyptian frontier. During the reign of his son Necho II (610–595 BC), Egypt supported Assyria as a buffer against the potential threat of the Medes and the Babylonians. Necho was successful in Palestine and Syria until 605 BC, when the Babylonian Nebuchadrezzar inflicted a severe defeat on Egyptian forces at Carchemish. After withdrawing his troops from Asia, Necho concentrated on developing Egyptian commerce; the grain that was delivered to Greece was paid for in silver. He also built up the navy and began a canal linking the Nile with the Red Sea. Under Psamtik II (ruled 595–589 BC) there was a campaign through the Napatan kingdom involving the use of Greek and Carian mercenaries who left their inscriptions at Abu Simbel; at the same time the names of the long-dead Cushite rulers were erased from their monuments in Egypt. Psamtik II also made an expedition to Phoenicia accompanied by priests; whether it was a military or a goodwill mission is unknown.

The next king, Apries (ruled 589–570 BC), tried unsuccessfully to end Babylonian domination of Palestine and Syria. With the withdrawal of Egyptian forces, Nebuchadrezzar destroyed the temple in Jerusalem in 586 BC. In the aftermath of his conquest, many Jews fled to Egypt, where some were enlisted as soldiers in the Persian army of occupation. Apries' army was then defeated in Libya when it attacked the Greek colony at Cyrene, some 620 miles west of the Delta; this led to an army mutiny and to civil war in the Delta. A new Saite king, Amasis (or Ahmose II; ruled 570–526 BC), usurped the throne and drove Apries into exile. Two years later Apries invaded Egypt with Babylonian support, but he was defeated and killed by Amasis, who nonetheless buried him with full honours. Amasis returned to a more conservative foreign policy in a long, prosperous reign. To reduce friction between Greeks and Egyptians, especially in the army, Amasis withdrew the Greeks from the military colonies and transferred them to Memphis, where they formed a sort of royal bodyguard. He limited Greek trade in Egypt to Sais, Memphis, and Naukratis, the latter becoming the only port to which Greek wares could be brought, so that taxes on imports and on business could be enforced. Naukratis prospered and Amasis was seen by the Greeks as a benefactor. In foreign policy he supported a waning Babylonia, now threatened by Persia; but six months after his death in 526 BC the Persian Cambyses II (ruled as pharaoh 525–522 BC) penetrated Egypt, reaching Nubia in 525.

Nationalism and cultural revival

As was common in the Near East in this period, the Saite kings used foreigners as mercenaries to prevent foreign invasions. An element within Egyptian culture, however, resisted any influence of the resident foreigners and gave rise to a nationalism that provided psychological security in days of political uncertainty. A cultural revival was initiated in the 25th dynasty and continued throughout the 26th. Temples and the priesthood were overtly dominant. In their inscriptions the elite displayed their priestly titles but did not mention the administrative roles that they probably also performed. Throughout the country, people of substance dedicated land to temple endowments that supplemented royal donations. The god Seth, who had been an antithetic element in Egyptian religion, came gradually to be proscribed as the god of foreign lands.

The revival of this period was both economic and cultural, but there is less archaeological evidence preserved than for earlier times because the economic centre of the country was now the Delta, where conditions for the preservation of ancient sites were unfavourable. Prosperity increased throughout the 26th dynasty, reaching a high point in the reign of Amasis. Temples throughout the land were added to, often in hard stones carved with great skill. The chief memorials of private individuals were often temple statues, of which many fine examples were dedicated, again mostly in hard stones. In temple and tomb decoration and in statuary, the Late Period rejected its immediate predecessors and looked to the great periods of the past for models. There was, however, also significant innovation. In writing, the demotic script, the new cursive form, was introduced from the north and spread gradually through the country. Demotic wrote a contemporary form of the language, and administrative Late Egyptian disappeared. Hieratic was, however, retained for literary and religious texts, among which very ancient material, such as the Pyramid Texts, was revived and inscribed in tombs and on coffins and sarcophagi.

The Late Period saw the greatest development of animal worship in Egypt. This feature of religion, which was the subject of much interest and scorn among classical writers, had always existed but had been of minor importance. In the Late and Ptolemaic periods, it became one of the principal forms of popular religion in an intensely religious society. Many species of animal were mummified and buried, and towns sprang up in the necropolises to cater for the needs of dead animals and their worshipers. At Saqqārah the Apis bull, which had been worshiped as a manifestation of the god Ptah since the 1st dynasty, was buried in a huge granite sarcophagus in ceremonies in which royalty might take part. At least 10 species, from ibises, buried by the million, to dogs, were buried by the

heterogeneous population of Memphis, Egypt's largest city.

Egypt under Achaemenid rule. *The 27th dynasty.* According to the Greek historian Herodotus, who visited Egypt around 450 BC, Cambyses II's conquest of Egypt was ruthless and sacrilegious. Contemporary Egyptian sources, however, treat him in a more favourable light. He assumed the full titulary of an Egyptian king and paid honour to the goddess Neith of Sais. His unfavourable later reputation probably resulted from adverse propaganda by Egyptian priests, who resented his reduction of temple income. Darius I, who succeeded Cambyses in 522 BC and ruled as pharaoh until 486 BC, was held in higher esteem because he was concerned with improving the temples and restored part of their income, and because he codified laws as they had been in the time of Amasis. These stances, which aimed to win over priests and learned Egyptians, were elements of his strategy to retain Egypt as a lasting part of the Persian Empire. Egypt, together with the Libyan oases and Cyrenaica, formed the sixth Persian satrapy (province), whose satrap resided at Memphis, while Persian governors under him held posts in cities throughout the land. Under Darius I the tax burden upon Egyptians was relatively light, and Persians aided Egypt's economy through irrigation projects and improved commerce, enhanced by the completion of the canal to the Red Sea.

The Persian defeat by the Athenians at Marathon in 490 BC had significant repercussions in Egypt. On Darius I's death in 486 BC a revolt broke out in the Delta, perhaps instigated by Libyans of the west Delta. The result was that the Persian king Xerxes reduced Egypt to the status of a conquered province. Egyptians dubbed him the "criminal Xerxes." He never visited Egypt and appears not to have utilized Egyptians in high positions in the administration. Xerxes' murder in 465 BC was the signal for another revolt in the western Delta. It was led by a dynast, Inaros, who acquired control over the Delta and was supported by Athenian forces against the Persians. Inaros was crucified by the Persians in 454 BC, when they regained control of most of the Delta. In the later 5th century BC, under the rule of Artaxerxes I (ruled as pharaoh 465–424 BC) and Darius II (ruled as pharaoh 424–404 BC), conditions in Egypt were very unsettled, and scarcely any monuments of the period have been identified.

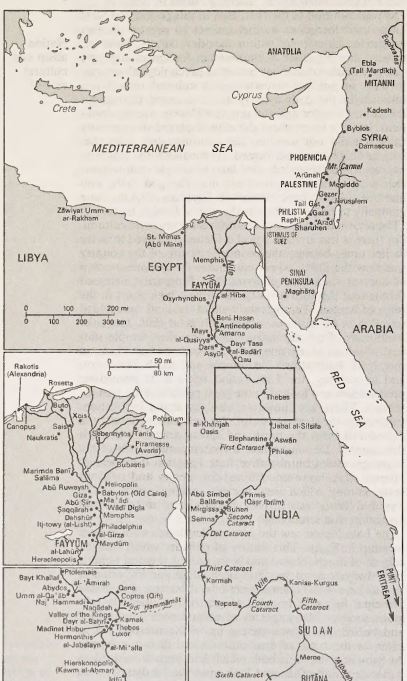
The 28th, 29th, and 30th dynasties. The death of Darius II in 404 BC prompted a successful rebellion in the Delta, and the Egyptian Amyrtaeus formed a Saite 28th dynasty, of which he was the sole king (404–399 BC). His rule was recognized in Upper Egypt by 401 BC, at a time when Persia's troubles elsewhere forestalled an attempt to regain Egypt.

Despite growing prosperity and success in retaining independence, 4th-century Egypt was characterized by continual internal struggle for the throne. After a long period of fighting in the Delta, a 29th dynasty (399–380 BC) emerged from Mendes. Achoris (ruled 393–380 BC), its third and final ruler, was especially vigorous, and the prosperity of his reign is indicated by many monuments in Upper and Lower Egypt. Once again Egypt was active in international politics, forming alliances with the opponents of Persia and building up its army and navy. The Egyptian army included Greeks both as mercenaries and as commanders; the mercenaries were not permanent residents of military camps in Egypt but native Greeks seeking payment for their services in gold. Payment was normally made in non-Egyptian coins, because as yet Egypt had no coinage in general circulation; the foreign coins may have been acquired in exchange for exports of grain, papyrus, and linen. Some Egyptian coins were minted in the 4th century, but they do not seem to have gained widespread acceptance.

Aided by the Greek commander Chabrias of Athens and his elite troops, Achoris prevented a Persian invasion; but after Achoris' death in 380 BC his son Nepherites II lasted only four months before a general, Nectanebo I (Nekhtnebef; ruled 380–362 BC) of Sebennytos, usurped the throne, founding the 30th dynasty (380–343 BC). In 373 BC the Persians attacked Egypt, and, although Egyptian losses were heavy, disagreement between the Persian satrap Pharnabazus and his Greek commander over strategy, combined with a timely inundation of the Delta, saved the day for Egypt. With the latent dissolution of the Persian Empire under the weak Artaxerxes II, Egypt was relatively safe from further invasion; it remained prosperous throughout the dynasty.

Egypt had a more aggressive foreign policy under Nectanebo's son Tachos (ruled *c.* 365–360 BC). Possessing a strong army and navy composed of Egyptian Machimoi and Greek mercenaries and supported by Chabrias and the Spartan king Agesilaus, Tachos (in Egyptian called Djeho) invaded Palestine. But friction between Tachos and Agesilaus and the cost of financing the venture proved to be Tachos' undoing. In an attempt to raise funds quickly, he had imposed taxes and seized temple property. Egyptians, especially the priests, resented this burden and supported Tachos' nephew Nectanebo II (Nekhtharehbe; ruled 360–343 BC) in his usurpation of the throne. The cost of retaining the allegiance of mercenaries proved too high for a nonmonetary economy.

Agesilaus supported Nectanebo in his defensive foreign policy, and the priests sanctioned the new king's building activities. Meanwhile, Persia enjoyed a resurgence under Artaxerxes III (Ochus); but a Persian attack upon Egypt in 350 BC was repulsed. In 343 BC the Persians once again marched against Egypt. The first battle was fought at Pelusium and proved the superiority of Persia's strategy.



Sites associated with Egypt from Predynastic to Byzantine times.

Eventually the whole Delta, then the rest of Egypt, fell to Artaxerxes III, and Nectanebo fled to Nubia.

The 4th century BC was the last flourishing period of an independent Egypt and saw notable artistic and literary achievements. The 26th dynasty artistic revival evolved further toward more complex forms that culminated briefly in a Greco-Egyptian stylistic fusion, as seen in the tomb of Petosiris at Tūnah al-Jabal from the turn of the 3rd century BC. In literature works continued to be transmitted, and possibly composed, in hieratic, but that tradition was to develop no further. Demotic literary works began to appear, including stories set in the distant past, mythological tales, and an acrostic text apparently designed to teach an order of sounds in the Egyptian language.

Return of Persian rule

The second Persian period. Artaxerxes dealt harshly with Egypt, razing city walls, rifling temple treasuries, and removing sacred books. Persia acquired rich booty in its determination to prevent Egypt from further rebelling. After the murder of Artaxerxes III, in 338 BC, there was a brief obscure period during which a Nubian prince, Khabbash, seems to have gained control over Egypt, but Persian domination was reestablished in 335 BC under Darius III Codommanus. It was to last only three years.

(E.F.W./J.R.Ba.)

MACEDONIAN AND PTOLEMAIC EGYPT (332–30 BC)

The Macedonian conquest. In the autumn of 332 BC Alexander the Great invaded Egypt with his mixed army of Macedonians and Greeks and found the Egyptians ready to throw off the oppressive control of the hated Persians. Alexander was welcomed by the Egyptians as a liberator and took the country without a battle. He journeyed to Siwa Oasis in the Western Desert to visit the Oracle of Amon, renowned in the Greek world; it disclosed the information that Alexander was the son of Amon. There may also have been a coronation at the Egyptian capital, Memphis, which, if it occurred, would have placed him firmly in the tradition of the pharaohs; the same purpose may be seen in the later dissemination of the romantic myth that gave him an Egyptian parentage by linking his mother, Olympias, with the last pharaoh, Nectanebo II.

Alexander's welcome in Egypt

Alexander left Egypt in the spring of 331 BC, dividing the military command between Balacrus, son of Amyntas, and Peucestas, son of Makartatos. The earliest known Greek documentary papyrus, found at Ṣaqqārah in 1973, reveals the sensitivity of the latter to Egyptian religious institutions in a notice that reads: "Order of Peucestas. No-one is to pass. The chamber is that of a priest." The civil administration was headed by an official with the Persian title of satrap, one Cleomenes of Naukratis. When Alexander died in 323 BC and his generals divided his empire, the position of satrap was claimed by Ptolemy, son of a Macedonian nobleman named Lagus. The senior general Perdiccas, the holder of Alexander's royal seal and prospective regent for Alexander's posthumous son, might well have regretted his failure to take Egypt. He gathered an army and marched from Asia Minor to wrest Egypt from Ptolemy in 321 BC; but Ptolemy had Alexander's corpse, Perdiccas' army was not wholehearted in support, and the Nile crocodiles made a good meal from the flesh of the invaders.

The Ptolemaic dynasty. Until the day when he openly assumed an independent kingship as Ptolemy I Soter, on Nov. 7, 305 BC, Ptolemy used only the title satrap of Egypt, but the great hieroglyphic Satrap stela, which he had inscribed in 311 BC, indicates a degree of self-confidence that transcends his viceregal role. It reads, "I, Ptolemy the satrap, I restore to Horus, the avenger of his father, the lord of Pe and to Buto, the lady of Pe and Dep, the territory of Patanut, from this day forth for ever, with all its villages, all its towns, all its inhabitants, all its fields." The inscription emphasizes Ptolemy's own role in wresting the land from the Persians (though the epithet of Soter, meaning "Saviour," resulted not from his actions in Egypt but from the gratitude of the people of Rhodes for his having relieved them from a siege in 315 BC) and links him with Khabbash, who had laid claim to the kingship during the last Persian occupation in about 338 BC.

Egypt was ruled by Ptolemy's descendants until the death of Cleopatra VII on Aug. 12, 30 BC. The kingdom was one of several that emerged in the aftermath of Alexander's death and struggles of his successors. It was the wealthiest, however, and, for much of the next 300 years, the most powerful politically and culturally, and it was the last to fall directly under Roman dominion. In many respects, the character of the Ptolemaic monarchy in Egypt set a style for other Hellenistic kingdoms; this style emerged from the Greeks' and Macedonians' awareness of the need to dominate Egypt, its resources, and its people and at the same time to turn the power of Egypt firmly toward the context of a Mediterranean world that was becoming steadily more Hellenized.

The Ptolemies (305–145 BC). The first 160 years of the Ptolemaic dynasty are conventionally seen as its most prosperous era. Little is known of the foundations laid in the reign of Ptolemy I Soter (304–282 BC), but the increasing amount of documentary, inscriptional, and archaeological evidence from the reign of his son and successor, Ptolemy II Philadelphus (285–246 BC), shows that the kingdom's administration and economy underwent a thorough reorganization. A remarkable demotic text of the year 258 BC refers to orders for a complete census of the kingdom that was to record the sources of water; the position, quality, and irrigation potential of the land; the state of cultivation; the crops grown; and the extent of priestly and royal landholdings. There were important agricultural innovations in this period. New crops were introduced, and massive irrigation works brought under cultivation a great deal of new land, especially in the Fayyūm, where many of the immigrant Greeks were settled.

Macedonian-Greek character of the monarchy

The Macedonian-Greek character of the monarchy was vigorously preserved. There is no more emphatic sign of this than the growth and importance of the city of Alexandria. It had been founded, on a date traditionally given as April 7, 331 BC, by Alexander the Great on the site of the insignificant Egyptian village of Rakotis in the northwestern Delta, and it ranked as the most important city in the eastern Mediterranean until the foundation of Constantinople in the 4th century AD. The importance of the new Greek city was soon emphasized by contrast to its Egyptian surroundings when the royal capital was transferred, within a few years of Alexander's death, from Memphis to Alexandria. The Ptolemaic court cultivated extravagant luxury in the Greek style in its magnificent and steadily expanding palace complex, which occupied as much as a third of the city by the early Roman period. Its grandeur was emphasized in the reign of Ptolemy II Philadelphus by the foundation of a quadrennial festival, the Ptolemaieia, which was intended to enjoy a status equal to that of the Olympic Games. The festival was marked by a procession of amazingly elaborate and ingeniously constructed floats, with scenarios illustrating Greek religious cults.

Ptolemy II gave the dynasty another distinctive feature when he married his full sister, Arsinoe II, one of the most powerful and remarkable women of the Hellenistic age. They became, in effect, co-rulers, and both took the epithet Philadelphus ("Brother-Loving" and "Sister-Loving"). The practice of consanguineous marriage was followed by most of their successors and imitated by ordinary Egyptians too, even though it had not been a standard practice in the pharaonic royal houses and had been unknown in the rest of the native Egyptian population. Arsinoe played a prominent role in the formation of royal policy. She was displayed on the coinage and was eventually worshiped, perhaps even before her death, in the distinctively Greek style of ruler cult that developed in this reign.

From the first phase of the wars of Alexander's successors the Ptolemies had harboured imperial ambitions. Ptolemy I won control of Cyprus and Cyrene and quarreled with his neighbour over control of Palestine. In the course of the 3rd century a powerful Ptolemaic empire developed, which, for much of the period, laid claim to sovereignty in the Levant, in many of the cities of the western and southern coast of Asia Minor, in some of the Aegean islands, and in a handful of towns in Thrace, as well as in Cyprus and Cyrene. Family connections and dynastic alliances, especially between the Ptolemies and the neigh-

Ptolemaic empire

bouring Seleucids, played a very important role in these imperialistic ambitions. Such links were far from able to preserve harmony between the royal houses (between 274 and 200 BC five wars were fought with the Seleucids over possession of territory in Syria and the Levant), but they did keep the ruling houses relatively compact, interconnected, and more true to their Macedonian-Greek origins.

When Ptolemy II Philadelphus died in 246 BC, he left a prosperous kingdom to his successor, Ptolemy III Euergetes (246–222 BC). His reign saw a very successful campaign against the Seleucids in Syria, occasioned by the murder of Euergetes' sister, Berenice, who had been married to the Seleucid Antiochus II. To avenge Berenice, Euergetes marched into Syria, where he won a great victory. He gained popularity at home by recapturing statues of Egyptian gods originally taken by the Persians. The decree promulgated at Canopus in the Delta on March 4, 238 BC, attests both this event and the many great benefactions conferred on Egyptian temples throughout the land. It was during Euergetes' reign, for instance, that the rebuilding of the great Temple of Horus at Idfū (Apollinopolis Magna) was begun.

Euergetes was succeeded by his son Ptolemy IV Philopator (222–205 BC), whom the Greek historians portray as a weak and corrupt ruler, dominated by a powerful circle of Alexandrian Greek courtiers. The reign was notable for another serious conflict with the Seleucids, which ended in 217 BC in a great Ptolemaic victory at Raphia in southern Palestine. The battle is notable for the fact that large numbers of native Egyptian soldiers fought alongside the Macedonian and Greek contingents. Events surrounding the death of Philopator and the succession of the youthful Ptolemy V Epiphanes (205–180 BC) are obscured by court intrigue. Before Epiphanes had completed his first decade of rule, serious difficulties arose. Native revolts in the south, which had been sporadic in the second half of the 3rd century, became serious and weakened the hold of the monarch on a vital part of the kingdom. These revolts, which produced native claimants to the kingship, are generally attributed to the native Egyptians' realization, after their contribution to the victory at Raphia, of their potential power. Trouble continued to break out for several more decades. By about 196 a great portion of the Ptolemaic overseas empire had been permanently lost (though there may have been a brief revival in the Aegean islands in about 165–145 BC). To shore up and advertise the strength of the ruling house at home and abroad, the administration adopted a series of grandiloquent honorific titles for its officers. To conciliate Egyptian feelings, a religious synod that met in 196 to crown Epiphanes at Memphis (the first occasion on which a Ptolemy is certainly known to have been crowned at the traditional capital) decreed extensive privileges for the Egyptian temples, as recorded on the Rosetta Stone.

Loss of the overseas empire

The reign of Ptolemy VI Philometor (180–145 BC), a man of pious and magnanimous character, was marked by renewed conflict with the Seleucids after the death of his mother, Cleopatra I, in 176 BC. In 170 BC Antiochus IV of Syria invaded Egypt and established a protectorate; in 168 BC he returned, accepted coronation at Memphis, and installed a Seleucid governor. But he had failed to reckon with more powerful interests: those of Rome. In the summer of 168 BC a Roman ambassador, Popillius Laenas, arrived at Antiochus' headquarters near Pelusium in the Delta and staged an awesome display of Roman power. He ordered Antiochus to withdraw from Egypt. Antiochus asked for time to consult his advisers. Laenas drew a circle around the King with his stick and told him to answer before he stepped out of the circle. Only one answer was possible, and by the end of July Antiochus had left Egypt. Philometor's reign was further troubled by rivalry with his brother, later Ptolemy VIII Euergetes II Physcon. The solution, devised under Roman advice, was to remove Physcon to Cyrene, where he remained until Philometor died in 145 BC; but it is noteworthy that in 155 BC Physcon took the step of bequeathing the kingdom of Cyrene to the Romans in the event of his untimely death.

Dynastic strife and decline (145–30 BC). Physcon was able to rule in Egypt until 116 BC with his sister Cleopatra II (except for a period in 131–130 BC when she was in revolt) and her daughter Cleopatra III. His reign was marked by generous benefactions to the Egyptian temples, but he was detested as a tyrant by the Greeks, and the historical accounts of the reign emphasize his stormy relations with the Alexandrian populace.

During the last century of Ptolemaic rule, Egypt's independence was exercised under Rome's protection and at Rome's discretion. For much of the period Rome was content to support a dynasty that had no overseas possession except Cyprus after 96 BC (the year in which Cyrene was bequeathed to Rome by Ptolemy Apion) and no ambitions threatening Roman interests or security. After a series of brief and unstable reigns, Ptolemy XII Auletes acceded to the throne in 80 BC. He maintained his hold for 30 years, despite the attractions that Egypt's legendary wealth held for avaricious Roman politicians. In fact, Auletes had to flee Egypt in 58 BC and was restored by Pompey's friend Gabinius in 55 BC, no doubt after spending so much in bribes that he had to bring back Rabirius Postumus, one of his Roman creditors, to Egypt with him to manage his financial affairs.

In 52 BC, the year before his death, Auletes associated with himself on the throne his daughter Cleopatra VII and his elder son Ptolemy XIII (who died in 47 BC). The reign of Cleopatra was that of a vigorous and exceptionally able queen who was ambitious, among other things, to revive the prestige of the dynasty by cultivating influence with powerful Roman commanders and using their capacity to aggrandize Roman clients and allies. Julius Caesar pursued Pompey to Egypt in 48 BC. After learning of Pompey's murder at the hands of Egyptian courtiers, Caesar stayed long enough to enjoy a sightseeing tour up the Nile in the Queen's company in the summer of 47 BC. When he left for Rome, Cleopatra was pregnant with a child she claimed was Caesar's. The child, a son, was named Caesarion ("Little Caesar"). Cleopatra and Caesarion later followed Caesar back to Rome but, after his assassination in 44 BC, they returned hurriedly to Egypt and she tried for a while to play a neutral role in the struggles between the Roman generals and their factions.

Reign of Cleopatra VII

Her long liaison with Mark Antony began when she visited him at Tarsus in 41 BC and he returned to Egypt with her. Between 36 and 30 BC the famous romance between the Roman general and the eastern queen was exploited to great effect by Antony's political rival Octavian. By 34 BC Caesarion was officially co-ruler with Cleopatra, but his rule clearly was an attempt to exploit the popularity of Caesar's memory. In the autumn Cleopatra and Antony staged an extravagant display in which they made grandiose dispositions of territory in the east to their children, Alexander Helios, Ptolemy, and Cleopatra Selene. Cleopatra and Antony were portrayed to the Roman public as posing for artists in the guise of Dionysus and Isis or whiling away their evenings in rowdy and decadent banquets that kept the citizens of Alexandria awake all night. But this propaganda war was merely the prelude to armed conflict, and the issue was decided in September 31 BC in a naval battle at Actium in western Greece. When the battle was at its height Cleopatra and her squadron withdrew, and Antony eventually followed suit. They fled to Alexandria but could do little more than await the arrival of the victorious Octavian 10 months later. Alexandria was captured and Antony and Cleopatra committed suicide—he by falling on his sword, she probably by the bite of an asp—in August of 30 BC. It is reported that when Octavian reached the city he visited and touched the preserved corpse of Alexander the Great, causing a piece of the nose to fall off. He refused to gaze upon the remains of the Ptolemies, saying "I wished to see a king, not corpses."

Government and conditions under the Ptolemies. The changes brought to Egypt by the Ptolemies were momentous; the land's resources were harnessed with unparalleled efficiency and the result was that it became the wealthiest of the Hellenistic kingdoms. Land under cultivation was increased, new crops were introduced (especially important was the introduction of naked tetraploid wheat, *triticum durum,* to replace the traditional husked emmer,

Improvements to agriculture

triticum dicoccum). The population, estimated at perhaps 3,000,000–4,000,000 in the Late Dynastic Period, may have more than doubled by the early Roman period to a figure of 7,500,000 or 8,000,000, a level not reached again until the late 19th century. Some of the increase was due to immigration; particularly during the 2nd and 3rd centuries many settlers were attracted from the cities of Asia Minor and the Greek islands, as well as large numbers of Jews from Palestine. The flow may have decreased later in the Ptolemaic period, and it is often suggested, on slender evidence, that there was a serious decline in prosperity in the 1st century BC. If so, there may have been some reversal of this trend under Cleopatra VII.

Administration. The foundation of the prosperity was the governmental system devised to exploit the country's economic resources. Directly below the monarch were a handful of powerful officials whose competence extended over the entire land: a chief finance minister, a chief accountant, and a chancery of ministers in charge of records, letters, and decrees. A level below them lay the broadening base of a pyramid of subordinate officials with competence in limited areas, which extended down to the chief administrator of each individual village (*kōmarchēs*). Between the chief ministers and the village officials stood those such as the nome-steward (*oikonomos*) and *stratēgoi*, whose competence extended over one of the more than 30 nomes of Egypt, the long-established geographic divisions. In theory this bureaucracy could regulate and control the economic activities of every subject in the land, its smooth operation guaranteed by the multiplicity of officials capable of checking each upon the other. In practice, it is difficult to see a rigid civil-service mentality at work, involving clear demarcation of departments; specific functions might well have been performed by different officials according to local need and the availability of a person competent to take appropriate action.

By the same token, rigid lines of separation between military and civil, legal and administrative matters are difficult to perceive. The same official might perform duties in one or all of these areas, and the law in particular regulated every activity to an extent that the use of the terms legal and judicial tends to hide. The military was inevitably integrated into civilian life because its soldiers were also farmers who enjoyed royal grants of land, either as Greek cleruchs (holders of allotments) with higher status and generous grants, or as native Egypt *machimoi* with small plots. Interlocking judiciary institutions, in the form of Greek and Egyptian courts (*chrēmatistai* and *laokritai*), provided the means for Greeks and Egyptians to regulate their legal relationships according to the language in which they conducted their business. The bureaucratic power was heavily weighted in favour of the Greek speakers, the dominant elite. Egyptians were nevertheless able to obtain official posts in the bureaucracy, gradually infiltrating to the highest levels, but in order to do so they had to Hellenize.

Economy. The basis of Egypt's legendary wealth was the highly productive land, which technically remained in royal ownership. A considerable portion was kept under the control of temples, and the remainder was leased out on a theoretically revocable basis to tenant-farmers. A portion also was available to be granted as gifts to leading courtiers; one of these was Apollonius, the finance minister of Ptolemy II Philadelphus, who had an estate of 10,000 arourae (about 6,500 acres) at Philadelphia in the Fayyūm. Tenants and beneficiaries were able to behave very much as if these leases and grants were private property. The revenues in cash and kind were enormous, and royal control extended to the manufacture and marketing of almost all important products, including papyrus, oil, linen, and beer. An extraordinarily detailed set of revenue laws, promulgated under Ptolemy II Philadelphus, laid down rules for the way in which officials were to monitor the production of such commodities. In fact, the Ptolemaic economy was very much a mixture of direct royal ownership and exploitation by private enterprise under regulated conditions.

Control of land

One fundamental and far-reaching Ptolemaic innovation was the systematic monetarization of the economy. This too the monarchy controlled from top to bottom by operating a closed monetary system, which permitted only the royal coinage to circulate within Egypt. A sophisticated banking system underpinned this practice, operating again with a mixture of direct royal control and private enterprise and handling both private financial transactions and those that directed money into and out of the royal coffers. One important concomitant of this change was an enormous increase in the volume of trade, both within Egypt and abroad, which eventually reached its climax under the peaceful conditions of Roman rule. Here the position and role of Alexandria as the major port and trading entrepôt was crucial: the city handled a great volume of Egypt's domestic produce, as well as the import and export of luxury goods to and from the East and the cities of the eastern Mediterranean. It developed its own importance as an artistic centre, the products of which found ready markets throughout the Mediterranean. Alexandrian glassware and jewelry were particularly fine; Greek-style sculpture of the late Ptolemaic period shows especial excellence; and it is likely that the city was also the major production centre for high-quality mosaic work.

Alexandria's importance to trade

Religion. The Ptolemies were powerful supporters of the native Egyptian religious foundations, the economic and political power of which was, however, carefully controlled. A great deal of the building and restoration work in many of the most important Egyptian temples is Ptolemaic, particularly from the period of about 150–50 BC, and the monarchs appear on temple reliefs in the traditional forms of the Egyptian kings. The native traditions persisted in village temples and local cults, many having particular associations with species of sacred animals or birds. At the same time, the Greeks created their own identifications of Egyptian deities, identifying Amon with Zeus, Horus with Apollo, Ptah with Hephaestus, and so on. They also gave some deities, such as Isis, a more universal significance that ultimately resulted in the spread of her mystery cult throughout the Mediterranean world. The impact of the Greeks is most obvious in two phenomena. One is the formalized royal cult of Alexander and the Ptolemies, which evidently served both a political and a religious purpose. The other is the creation of the cult of Sarapis, which at first was confined to Alexandria but soon became universal. The god was represented as a Hellenized deity and the form of cult is Greek; but its essence is the old Egyptian notion that the sacred Apis bull merged its divinity in some way with the god Osiris when it died.

Greek identifications of Egyptian deities

Culture. The continuing vitality of the native Egyptian artistic tradition is clearly and abundantly expressed in the temple architecture and the sculpture of the Ptolemaic period. The Egyptian language continued in use in its hieroglyphic and demotic forms until late in the Roman period, and it survived through the Byzantine period and beyond in the form of Coptic. The Egyptian literary tradition flourished vigorously in the Ptolemaic period and produced a large number of works in demotic. The genre most commonly represented is the romantic tale, exemplified by several story cycles, which are typically set in the native, Pharaonic milieu and involve the gods, royal figures, magic, romance, and the trials and combats of heroes. Another important category is the Instruction Text, the best known of the period being that of Ankhsheshonq, which consists of a list of moralizing maxims, composed, as the story goes, when Ankhsheshonq was imprisoned for having failed to inform the pharaoh of an assassination plot. Another example, known as Papyrus Insinger, is a more narrowly moralizing text. But the arrival of a Greek-speaking elite had an enormous impact on cultural patterns. The Egyptian story cycles were probably affected by Greek influence; literary and technical works were translated into Greek; and under royal patronage an Egyptian priest named Manetho of Sebennytos wrote an account of the kings of Egypt, in Greek. Most striking is the diffusion of the works of the poets and playwrights of classical Greece among the literate Greeks in the towns and villages of the Nile Valley.

Influence of Greek on the literature

Thus there are clear signs of the existence of two interacting but distinct cultural traditions in Ptolemaic Egypt.

This was certainly reflected in a broader social context. The written sources offer little direct evidence of racial discrimination by Greeks against Egyptians, but Greek and Egyptian consciousness of the Greeks' social and economic superiority comes through strongly from time to time; intermarriage was one means, though not the only one, by which Egyptians could better their status and Hellenize. Many native Egyptians learned to speak Greek, some to write it as well; some even went so far as to adopt Greek names in an attempt to assimilate themselves to the elite group.

Hellenization of the Egyptians

Alexandria occupied a unique place in the history of literature, ideas, scholarship, and science for almost a millennium after the death of its founder. Under the royal patronage of the Ptolemies, and in an environment almost oblivious to its Egyptian surroundings, Greek culture was preserved and developed. Early in the Ptolemaic period, probably in the reign of Ptolemy I Soter, the Museum ("Shrine of the Muses") was established within the palace complex. Strabo, who saw it early in the Roman period, described it as having a covered walk, an arcade with recesses and seats, and a large house containing the dining hall of the members of the Museum, who lived a communal existence. The Great Library of Alexandria (together with its offshoot in the Sarapeum) was indispensable to the functioning of the scholarly community in the Museum. Books were collected voraciously under the Ptolemies, and at its height the library's collection probably numbered close to 500,000 papyrus rolls, most of them containing more than one work.

Poets and scholars at Alexandria

The major poets of the Hellenistic period, Theocritus, Callimachus, and Apollonius of Rhodes, all took up residence and wrote there. Scholarship flourished, preserving and ordering the manuscript traditions of much of the classical literature from Homer onward. Librarian-scholars such as Aristophanes of Byzantium and his pupil Aristarchus made critical editions and wrote commentaries and works on grammar. Also notable was the cultural influence of Alexandria's Jewish community, which is inferred from the fact that the Pentateuch was first translated into Greek at Alexandria during the Ptolemaic period. One by-product of this kind of activity was that Alexandria became the centre of the book trade, and the works of the classical authors were copied there and diffused among a literate Greek readership scattered in the towns and villages of the Nile Valley.

The Alexandrian achievement in scientific fields was also enormous. Great advances were made in pure mathematics, mechanics, physics, geography, and medicine. Euclid worked in Alexandria in about 300 BC and achieved the systematization of the whole existing corpus of mathematical knowledge and the development of the method of proof by deduction from axioms. Archimedes was there in the 3rd century BC and is said to have invented the Archimedean screw when he was in Egypt; Eratosthenes calculated the Earth's circumference and was the first to attempt a map of the world based on a system of lines of latitude and longitude; and the school of medicine founded in the Ptolemaic period retained its leading reputation into the Byzantine era. Late in the Ptolemaic period Alexandria began to develop as a great centre of Greek philosophical studies as well. In fact, there was no field of literary, intellectual, or scientific activity to which Ptolemaic Alexandria failed to make an important contribution. (A.E.S./A.K.B.)

ROMAN AND BYZANTINE EGYPT (30 BC–AD 642)

Egypt as a province of Rome. "I added Egypt to the Empire of the Roman people." With these words the emperor Augustus (as Octavian was known from 27 BC) summarized the subjection of Cleopatra's kingdom in the great inscription that records his achievements. The province was to be governed by a viceroy, a prefect with the status of a Roman knight (eques) who was directly responsible to the emperor. The first viceroy was the Roman poet and soldier Cornelius Gallus, who boasted too vainglorioously of his military achievements in the province and paid for it first with his position and then with his life. Roman senators were not allowed to enter Egypt without the emperor's permission, because this wealthiest of provinces could be held militarily by a very small force; and the threat implicit in an embargo on the export of grain supplies, vital to the provisioning of the city of Rome and its populace, was obvious. Internal security was guaranteed by the presence of three Roman legions (later reduced to two), each about 6,000 strong, and several cohorts of auxiliaries. In the first decade of Roman rule the spirit of Augustan imperialism looked farther afield, attempting expansion to the east and to the south. An expedition to Arabia by the prefect Aelius Gallus in about 26–25 BC was undermined by the treachery of the Nabataean Syllaeus, who led the Roman fleet astray in uncharted waters. Arabia was to remain an independent though friendly client of Rome until AD 106, when the emperor Trajan (ruled AD 98–117) annexed it, making it possible to reopen Ptolemy II's canal from the Nile to the head of the Gulf of Suez. To the south the Meroitic people beyond the First Cataract had taken advantage of Gallus' preoccupation with Arabia and mounted an attack on the Thebaid. The next Roman prefect, Petronius, led two expeditions into the Meroitic kingdom (*c.* 24–22 BC), captured several towns, forced the submission of the formidable queen, who was characterized by Roman writers as "the one-eyed Queen Candace," and left a Roman garrison at Primis (Qaṣr Ibrīm). But thoughts of maintaining a permanent presence in Lower Nubia were soon abandoned, and within a year or two the limits of Roman occupation had been set at Hiera Sykaminos, some 50 miles south of the First Cataract. The mixed character of the region is indicated, however, by the continuing popularity of the goddess Isis among the people of Meroe and by the Roman emperor Augustus' foundation of a temple at Kalabsha dedicated to the local god Mandulis.

Attempts to expand Rome's territory

Egypt achieved its greatest prosperity under the shadow of the Roman peace which, in effect, depoliticized it. Roman emperors or members of their families visited Egypt—Tiberius' nephew and adopted son, Germanicus; Vespasian and his elder son, Titus; Hadrian; Septimius Severus; Diocletian—to see the famous sights, receive the acclamations of the Alexandrian populace, attempt to ensure the loyalty of the volatile subjects, or initiate administrative reform. Occasionally its potential as a power base was realized. Vespasian, the most successful of the imperial aspirants in the "Year of the Four Emperors," was first proclaimed at Alexandria on July 1, AD 69, in a maneuver contrived by the prefect of Egypt, Tiberius Julius Alexander. Others were less successful. Avidius Cassius, the son of a former prefect of Egypt, revolted against Marcus Aurelius in AD 175, stimulated by false rumours of Marcus' death, but his attempted usurpation lasted only three months. For several months in AD 297/298 Egypt was under the dominion of a mysterious usurper named Lucius Domitius Domitianus. The emperor Diocletian was present at the final capitulation of Alexandria after an eight-month siege and swore to take revenge by slaughtering the populace until the river of blood reached his horse's knees; the threat was mitigated when his mount stumbled as he rode into the city. In gratitude, the citizens of Alexandria erected a statue of the horse.

The only extended period during the turbulent 3rd century AD in which Egypt was lost to the central imperial authority was 270–272, when it fell into the hands of the ruling dynasty of the Syrian city of Palmyra. Fortunately for Rome, the military strength of Palmyra proved to be the major obstacle to the overrunning of the Eastern Empire by the powerful Sāsānian monarchy of Persia.

Internal threats to security were not uncommon but normally were dissipated without major damage to imperial control. These included rioting between Jews and Greeks in Alexandria in the reign of Caligula (Gaius Caesar Germanicus; ruled AD 37–41); a serious Jewish revolt under Trajan (ruled AD 98–117); a revolt in the Delta in AD 172 that was quelled by Avidius Cassius; and a revolt centred on the town of Coptos (Qift) in AD 293/294 that was put down by Galerius, Diocletian's imperial colleague.

Revolts against Rome

Administration and economy under Rome. The Romans introduced important changes in the administrative system, aimed at achieving a high level of efficiency and

maximizing revenue. The duties of the prefect of Egypt combined responsibility for military security through command of the legions and cohorts, for the organization of finance and taxation, and for the administration of justice. This involved a vast mass of detailed paperwork: one document of AD 211 notes that in a period of three days 1,804 petitions were handed into the prefect's office. But the prefect was assisted by a hierarchy of subordinate equestrian officials with expertise in particular areas. There were three or four *epistratēgoi* in charge of regional subdivisions; special officers were in charge of the emperors' private account, the administration of justice, religious institutions, and so on. Subordinate to them were the local officials in the nomes (*stratēgoi* and royal scribes) and finally the authorities in the towns and villages.

It was in these growing towns that the Romans made the most far-reaching changes in administration. They introduced colleges of magistrates and officials who were to be responsible for running the internal affairs of their own communities on a theoretically autonomous basis and, at the same time, were to guarantee the collection and payment of tax quotas to the central government. This was backed up by the development of a range of "liturgies," compulsory public services that were imposed on individuals according to rank and property to ensure the financing and upkeep of local facilities. These institutions were the Egyptian counterpart of the councils and magistrates that oversaw the Greek cities in the eastern Roman provinces. They had been ubiquitous in other Hellenistic kingdoms, but in Ptolemaic Egypt they had existed only in the so-called Greek cities (Alexandria, Ptolemais in Upper Egypt, Naukratis, and later Antinoöpolis, founded by Hadrian in AD 130). Alexandria lost the right to have a council, probably in the Ptolemaic period. When it recovered its right in AD 200 the privilege was diluted by being extended to the nome capitals (*mētropoleis*) as well. This extension of privilege represented an attempt to shift more of the burden and expense of administration onto the local propertied classes, but it was eventually to prove too heavy. The consequences were the impoverishment of many of the councillors and their families and serious problems in administration that led to an increasing degree of central government interference and, eventually, more direct control.

Taxation under Roman rule

The economic resources that this administration existed to exploit had not changed since the Ptolemaic period, but the development of a much more complex and sophisticated taxation system was a hallmark of Roman rule. Taxes in both cash and kind were assessed on land, and a bewildering variety of small taxes in cash, as well as customs dues and the like, was collected by appointed officials. A massive amount of Egypt's grain was shipped downriver both to feed the population of Alexandria and for export to Rome. Despite frequent complaints of oppression and extortion from the taxpayers, it is not obvious that official tax rates were very high. In fact the Roman government had actively encouraged the privatization of land and the increase of private enterprise in manufacture, commerce, and trade, and low tax rates favoured private owners and entrepreneurs. The poorer people gained their livelihood as tenants of state-owned land or of property belonging to the emperor or to wealthy private landlords, and they were relatively much more heavily burdened by rentals, which tended to remain at a fairly high level.

Overall, the degree of monetarization and complexity in the economy, even at the village level, was intense. Goods were moved around and exchanged through the medium of coin on a large scale and, in the towns and the larger villages, a high level of industrial and commercial activity developed in close conjunction with the exploitation of the predominant agricultural base. The volume of trade, both internal and external, reached its peak in the 1st and 2nd centuries AD. But by the end of the 3rd century AD, major problems were evident. A series of debasements of the imperial currency had undermined confidence in the coinage, and even the government itself was contributing to this by demanding more and more irregular tax payments in kind, which it channeled directly to the main consumers, the army personnel. Local administration by the councils was careless, recalcitrant, and inefficient; the evident need for firm and purposeful reform had to be squarely faced in the reigns of Diocletian and Constantine.

Society, religion, and culture. One of the more noticeable effects of Roman rule was the clearer tendency to classification and social control of the populace. Thus, despite many years of intermarriage between Greeks and Egyptians, lists drawn up in AD 4/5 established the right of certain families to class themselves as Greek by descent and to claim privileges attaching to their status as members of an urban aristocracy, known as the gymnasial class. Members of this group were entitled to lower rates of poll tax, subsidized or free distributions of food, and maintenance at the public expense when they grew old. If they or their descendants were upwardly mobile, they might gain Alexandrian citizenship, Roman citizenship, or even equestrian status, with correspondingly greater prestige and privileges. The preservation of such distinctions was implicit in the spread of Roman law and was reinforced by elaborate codes of social and fiscal regulations such as the "Rule-Book of the Emperors' Special Account." The "Rule-Book" prescribed conditions under which people of different status might marry, for instance, or bequeath property and fixed fines, confiscations, and other penalties for transgression. When an edict of the emperor Caracalla conferred Roman citizenship on practically all of the subjects of the empire in AD 212, the distinction between citizens and noncitizens became meaningless; but it was gradually replaced by an equally important distinction between *honestiores* and *humiliores* (meaning, roughly, upper and lower classes), groups that, among other distinctions, were subjected to different penalities in law.

Social and fiscal codes

Naturally, it was the Greek-speaking elite that continued to dictate the visibly dominant cultural pattern, though Egyptian culture was not moribund or insignificant; one proof of its continued survival can be seen in its reemergent importance in the context of Coptic Christianity in the Byzantine period. An important reminder of the mixing of the traditions comes from a family of Panopolis in the 4th century, whose members included both teachers of Greek oratory and priests in Egyptian cult. The towns and villages of the Nile Valley have preserved thousands of papyri that show what the literate Greeks were reading: the poems of Homer and the lyric poets, works of the classical Greek tragedians, and comedies of Menander, for example. The pervasiveness of the Greek literary tradition is strikingly demonstrated by evidence left by an obscure and anonymous clerk at the Fayyūm village of Karanis in the 2nd century AD. In copying out a long list of taxpayers, the clerk translated an Egyptian name in the list by an extremely rare Greek word that he could only have known from having read the Alexandrian Hellenistic poet Callimachus; he must have understood the etymology of the Egyptian name as well.

Alexandria continued to develop as a spectacularly beautiful city and to foster Greek culture and intellectual pursuits, though the great days of Ptolemaic court patronage of literary figures had passed. But the flourishing interest in philosophy, particularly Platonic, had important effects. The great Jewish philosopher and theologian of the 1st century, Philo of Alexandria, brought a training in Greek philosophy to bear on his commentaries on the Old Testament. This anticipates by a hundred years the period after the virtual annihilation of the great Jewish community of Alexandria in the revolt of AD 115–117, when the city was the intellectual crucible in which Christianity developed a theology that took it away from the influence of the Jewish exegetical tradition and toward that of Greek philosophical ideas. There the foundations were laid for the teaching of the heads of the Christian catechetical school, such as Clement of Alexandria. And in the 3rd century there was the vital textual and theological work of Origen, the greatest of the Christian Neoplatonists, without which there would hardly have been a coherent New Testament tradition at all.

Outside the Greek ambience of Alexandria, traditional Egyptian religious institutions continued to flourish in the towns and villages; but the temples were reduced to financial dependence on a state subvention (*syntaxis*) and they

became subject to stringent control by secular bureaucrats. Nevertheless, like the Ptolemies before them, Roman emperors appear in the traditional form as Egyptian kings on temple reliefs until the middle of the 3rd century; and five professional hieroglyph cutters were still employed at the town of Oxyrhynchus in the 2nd century. The animal cults continued to flourish, despite Augustus' famous sneer that he was accustomed to worship gods, not cattle. As late as the reign of Diocletian (AD 285–305) religious stelae preserved the fiction that in the cults of sacred bulls (best known at Memphis and at Hermonthis), the successor of a dead bull was "installed" by the monarch. Differences between cults of the Greek type and the native Egyptian cults were still very marked, in the temple architecture as in the status of the priests. Priests of Egyptian cult formed, in effect, a caste distinguished by their special clothing, whereas priestly offices in Greek cult were much more like magistracies and tended to be held by local magnates. Cult of Roman emperors, living and dead, became universal after 30 BC, but its impact is most clearly to be seen in the foundations of Caesarea (Temples of Caesar) and in religious institutions of Greek type, where divine emperors were associated with the resident deities.

Egyptian and Roman cults

One development that did have an important effect on this pagan religious amalgam, though it was not decisive until the 4th century, was the arrival of Christianity. The tradition of the foundation of the church of Alexandria by St. Mark cannot be substantiated, but a fragment of a text of the Gospel According to John provides concrete evidence of Christianity in the Nile Valley in the second quarter of the 2nd century AD. Inasmuch as Christianity remained illegal and subject to persecution until the early 4th century, Christians were reluctant to advertise themselves as such, and it is therefore difficult to know how numerous they were, especially because later pro-Christian sources may often be suspected of exaggerating the zeal and the numbers of the early Christian martyrs. But several papyri survive of the *libelli* submitted in the first official state-sponsored persecution of Christians, under the emperor Decius (ruled 249–251): these were certificates in which people swore that they had performed sacrifices to pagan gods in order to prove that they were not Christians. By the 290s, a decade or so before the great persecution of Diocletian, a list of buildings in the sizeable town of Oxyrhynchus, some 125 miles south of the apex of the delta, included two Christian churches, probably of the house-chapel type.

Arrival of Christianity

Egypt's role in the Byzantine Empire. Diocletian was the last reigning Roman emperor to visit Egypt, in AD 302. Within about 10 years of his visit, the persecution of Christians ceased. The end of persecution had such far-reaching effects that from this point on it is necessary to think of the history of Egypt in a very different framework. No single point can be identified as the watershed between the Roman and Byzantine periods, as the divide between the peace, culture, and prosperity of the Principate and the darker age of the Dominate, supposedly characterized by a more oppressive state machinery in the throes of decline and fall. The crucial changes occurred in the last decade of the 3rd century and the first three decades of the 4th. With the end of persecution of Christians came the restoration of the property of the church. In 313 a new system of calculating and collecting taxes was introduced, with 15-year tax cycles, called indictions, inaugurated retrospectively from the year 312. Many other important administrative changes had already taken place. In 296 the separation of the Egyptian coinage from that of the rest of the empire had come to an end when the Alexandrian mint stopped producing its tetradrachmas, which had been the basis of the closed currency system.

One other event that had an enormous effect on the political history of Egypt was the founding of Constantinople on May 11, 330. First, Constantinople was established as an imperial capital and an eastern counterpart to Rome itself, thus undermining Alexandria's traditional position as the first city of the Greek-speaking East. Second, it diverted the resources of Egypt away from Rome and the West. Henceforth, part of the surplus of the Egyptian grain supply, which was put at 8,000,000 *artabs* (about 300,000,000 litres) of wheat in an edict of the emperor Justinian of about 537 or 538, went to feed the growing population of Constantinople, and this created an important political and economic link. The cumulative effect of these changes was to knit Egypt more uniformly into the structure of the empire and to give it, once again, a central role in the political history of the Mediterranean world.

Founding of Constantinople and its effect on Egypt

The key to understanding the importance of Egypt in this period lies in seeing how the Christian Church came rapidly to dominate secular as well as religious institutions and to acquire a powerful interest and role in every political issue. The corollary of this was that the head of the Egyptian Church, the patriarch of Alexandria, became the most influential figure within Egypt, as well as the person who could give the Egyptian clergy a powerful voice in the councils of the Eastern Church. During the course of the 4th century, Egypt was divided for administrative purposes into a number of smaller units but the patriarchy was not, and its power thus far outweighed that of any local administrative official. Only the governors of groups of provinces (*vicarii* of dioceses) were equivalent, the praetorian prefects and emperors superior; and when a patriarch of Alexandria was given civil authority as well, as happened in the case of Cyrus, the last patriarch under Byzantine rule, the combination was very powerful indeed.

The turbulent history of Egypt in the Byzantine period can largely be understood in terms of the struggles of the successive (or, after AD 570, coexisting) patriarchs of Alexandria to maintain their position both within their patriarchy and outside it in relation to Constantinople. What linked Egypt and the rest of the Eastern Empire was the way in which the imperial authorities, when strong (as, for instance, in the reign of Justinian), tried to control the Egyptian Church from Constantinople, while at the same time assuring the capital's food supply and, as often as not, waging wars to keep their empire intact. Conversely, when weak they failed to control the church. For the patriarchs of Alexandria, it proved impossible to secure the approval of the imperial authorities in Constantinople and at the same time maintain the support of their power base in Egypt. The two made quite different demands, and the ultimate result was a social, political, and cultural gulf between Alexandria and the rest of Egypt, and between Hellenism and native Egyptian culture, which found a powerful new means of expression in Coptic Christianity. The gulf was made more emphatic after the Council of Chalcedon in 451 established the official doctrine that Christ was to be seen as existing in two natures, inseparably united. The council's decision in effect sent the Egyptian Coptic (now Coptic Orthodox) Church off on its own path of Monophysitism, which centred around a firm insistence on the singularity of the nature of Christ.

Power of the patriarchs of Alexandria

Despite the debilitating effect of internal quarrels between rival churchmen, and despite the threats posed by the hostile tribes of Blemmyes and Nubade in the south (until their conversion to Christianity in the mid-6th century), emperors of Byzantium still could be threatened by the strength of Egypt if it were properly harnessed. The last striking example is the case of the emperor Phocas, a tyrant who was brought down in 609 or 610. Nicetas, the general of the future emperor Heraclius, made for Alexandria from Cyrene, intending to use Egypt as his power base and cut off Constantinople's grain supply. By the spring of 610 Nicetas' struggle with Bonosus, the general of Phocas, was won, and the fall of the tyrant duly followed.

The difficulty of defending Egypt from a power base in Constantinople was forcefully illustrated during the last three decades of Byzantine rule. First, the old enemy, the Persians, advanced to the Nile Delta and captured Alexandria. Their occupation was completed early in 619 and continued until 628, when Persia and Byzantium agreed to a peace treaty and the Persians withdrew. This had been a decade of violent hostility to the Egyptian Coptic Christians; among other oppressive measures, the Persians are said to have refused to allow the normal ordination of bishops and to have massacred hundreds of monks in their cave monasteries. The Persian withdrawal hardly heralded the return of peace to Egypt.

In Arabia events were taking place that would soon

bring momentous changes for Egypt. These were triggered by the flight of the Prophet Muḥammad from Mecca to Medina and by his declaration in AD 632 of a holy Islāmic war against Byzantium. Ten years later, by Sept. 29, 642, the Arab general ʿAmr ibn al-ʿĀṣ was able to march into Alexandria, and the Arab conquest of Egypt, which had begun with an invasion three years earlier, ended in peaceful capitulation. The invasion itself had been preceded by several years of vicious persecution of Coptic Christians by the Chalcedonian patriarch of Alexandria, Cyrus, and it was he who is said to have betrayed Egypt to the forces of Islām.

Islāmic conquest of Egypt

The Islāmic conquest was not bloodless. There was desultory fighting at first in the eastern Delta, then the Fayyūm was lost in battle in 640, and a great battle took place at Heliopolis (now a suburb of Cairo) in July 640 in which 15,000 Arabs engaged 20,000 Egyptian defenders. The storming and capture of Trajan's old fortess at Babylon (on the site of the present-day quarter called Old Cairo) on April 6, 641, was crucial. By September 14 Cyrus, who had been recalled from Egypt 10 months earlier by the emperor Heraclius, was back with authority to conclude a peace. Byzantium signed Egypt away on Nov. 8, 641, with provision for an 11-month armistice to allow ratification of the treaty of surrender by the emperor and the caliph. In December 641 heavily laden ships were dispatched to carry Egypt's wealth to its new masters. Nine months later the last remnants of Byzantine forces had left Egypt in ships bound for Cyprus, Rhodes, and Constantinople, and ʿAmr ibn al-ʿĀṣ had taken Alexandria in the name of the caliph. The new domination by the theocratic Islāmic caliphate was more strikingly different than anything that had happened in Egypt since the arrival of Alexander the Great almost a thousand years earlier.

Byzantine government of Egypt. The reforms of the early 4th century had established the basis for another 250 years of comparative prosperity in Egypt, at a cost of perhaps greater rigidity and more oppressive state control. Egypt was subdivided for administrative purposes into a number of smaller provinces, and separate civil and military officials were established (the *praeses* and the *dux*). By the middle of the 6th century the emperor Justinian was eventually forced to recognize the failure of this policy and to combine civil and military power in the hands of the *dux* with a civil deputy (the *praeses*) as a counterweight to the power of the church authorities. All pretense of local autonomy had by then vanished. The presence of the soldiery was more noticeable, its power and influence more pervasive in the routine of town and village life. Taxes were perhaps not heavier than they had been earlier, but they were collected ruthlessly, and strong measures were sanctioned against those who tried to escape from their fiscal or legal obligations. The wealthier landowners probably enjoyed increased prosperity, especially as a result of the opportunity to buy state-owned land that had been sold into private ownership in the early 4th century. The great landlords were powerful enough to offer their peasant tenants a significant degree of collective fiscal protection against the agents of the state, the rapacious tax collector, the officious bureaucrat, or the brutal soldier. But, if the life of the average peasant did not change much, nevertheless the rich probably became richer, and the poor became poorer and more numerous as the moderate landholders were increasingly squeezed out of the picture.

The advance of Christianity. The advance of Christianity had just as profound an effect on the social and cultural fabric of Byzantine Egypt as on the political power structure. It brought to the surface the identity of the native Egyptians in the Coptic Church, which found a medium of expression in the development of the Coptic language—basically Egyptian written in Greek letters with the addition of a few characters. Coptic Christianity developed its own distinctive art too, much of it pervaded by the long-familiar motifs of Greek mythology. These motifs coexisted with representations of the Virgin and Child and with Christian parables and were expressed in decorative styles that owed a great deal to both Greek and Egyptian precedents. Although Christianity had made great inroads into the populace by AD 391, the year in which the practice of pagan religion was officially made illegal, it is hardly possible to quantify it or to trace a neat and uniform progression. It engulfed its pagan precedents slowly and untidily. In the first half of the 5th century a pagan literary revival occurred, centred on the town of Panopolis, and there is evidence that fanatical monks in the area attacked pagan temples and stole statues and magical texts. Outside the rarefied circles in which doctrinal disputes were discussed in philosophical terms, there was a great heterogeneous mass of commitment and belief. Both the Gnostics, who believed in redemption through knowledge, and the Manichaeans, followers of the Persian prophet Mani, for example, clearly thought of themselves as Christians. In the 4th century a Christian community, the library of which was discovered at Naj' Ḥammādi in 1945, was reading both canonical and apocryphal gospels as well as mystical revelatory tracts. At the lower levels of society pagan magical practices remained ubiquitous and were simply converted into a Christian context.

The Egyptian Coptic Church

By the middle of the 5th century Egypt's landscape was dominated by the great churches, such as the magnificent Church of St. Menas (Abū Mīna), south of Alexandria, and by the monasteries. The latter were Egypt's distinctive contribution to the development of Christianity and were particularly important as strongholds of native loyalty to the Monophysite Church. The origins of Antonian communities, named for the founding father of monasticism, St. Anthony of Egypt (*c.* 251–356), lay in the desire of individuals to congregate about the person of a celebrated ascetic in a desert location, building their own cells, adding a church and a refectory, and raising towers and walls to enclose the unit. Other monasteries, called Pachomian after Pachomius, the founder of cenobitic monasticism, were planned from the start as walled complexes with communal facilities. The provision of water cisterns, kitchens, bakeries, oil presses, workshops, stables, and cemeteries and the ownership and cultivation of land in the vicinity made these communities self-sufficient to a high degree, offering their residents peace and protection against the oppression of the tax collector and the brutality of the soldier. But it does not follow that they were divorced from contact with nearby towns and villages. Indeed, many monastics were important local figures and many monastery churches were probably open to the local public for worship.

Monasticism in Egypt

The economic and social power of the Christian Church in the Nile Valley and Delta is the outstanding development of the 5th and 6th centuries. By the time of the Arab invasion, in the mid-7th century, the uncomplicated propaganda of Islām might have seemed attractive and drawn attention to the political and religious rifts that successive and rival patriarchs of the Christian Church had so violently created and exploited. But the advent of Arab rule did not suppress Christianity in Egypt. Some areas remained heavily Christian for several centuries more.

(A.K.B.)

FROM THE ISLĀMIC CONQUEST TO 1250

Medieval Egyptian history opens and closes with foreign conquests of Egypt: the Arab invasion led by ʿAmr ibn al-ʿĀṣ in 639 and the Napoleonic expedition of 1798 mark the beginning and end of an era. Within the context of Egyptian internal history alone, this era was one in which Egypt cast off the heritage of the past to embrace a new language and a new religion—in other words, a new culture. While it is true that the past was by no means immediately and completely abandoned and that many aspects of Egyptian life, especially rural life, continued virtually unchanged, it is nevertheless clear that the civilization of Islāmic Egypt diverged sharply from that of the Greco-Roman period and was transformed under the impact of Western occupation. The history of medieval Egypt is therefore largely a study of the processes by which Egyptian Islāmic civilization evolved, particularly the processes of Arabization and Islāmization. But to confine Egyptian history to internal developments is to distort it, for during the entire medieval period Egypt was a part of a great world empire; and within this broader context, Egypt's history is a record of its long struggle to dominate

an empire—a struggle that is not without its parallels, of course, in both ancient and modern times.

The Arab expedition to Egypt

Period of Arab and Turkish governors (639–868). The sending of a military expedition to Egypt from the caliphal capital in Medina came in a second phase of the first Arab conquests. Theretofore the conquests had been directed against lands on the northern borders of Arabia and were in the nature of raids for plunder; they had grown in scale and momentum as the Byzantines and Persians put up organized resistance. By 635 the Arabs had realized that in order to meet this resistance effectively they must begin the systematic occupation of enemy territory, especially Syria, where the Byzantine army was determined to halt the Arab forays.

The Arab conquest. The Arabs defeated the Byzantines and occupied the key cities of Syria and Palestine, and they vanquished the Persian army on the eastern front in Mesopotamia and Iraq. The next obvious step was to secure Syria against a possible attack launched from the Byzantine province of Egypt. Beyond this strategic consideration, Arab historians call attention to the fact that 'Amr ibn al-'Āṣ, the Arab general who later conquered Egypt, had visited Alexandria as a youth and had himself witnessed Egypt's enormous wealth. In spite of the obvious economic gain to be had from conquering Egypt, the caliph 'Umar, according to some sources, showed reluctance to detach 'Amr's expedition from the Syrian army and even tried to recall the mission once it had embarked; but 'Amr, with or without the Caliph's permission, undertook the invasion in 639 with a small army of some 4,000 men (later reinforced). With what seems astonishing speed the Byzantine forces were routed and had withdrawn from Egypt by 642. An attempt by a Byzantine fleet and army to reconquer Alexandria in 645 was quickly defeated by the Arabs.

Various explanations have been given for the speed with which the conquest was achieved, most of which stress the weakness of Byzantine resistance rather than Arab strength. Certainly the division of the Byzantine government and army into autonomous provincial units militated against the possibility of a concerted and coordinated response. Although there is only dubious evidence for the claim that the Copts welcomed the Arab invasion in the belief that Muslim religious tolerance would be preferable to Byzantine enforced orthodoxy and repression, Coptic support for their Byzantine oppressors was probably unenthusiastic at best.

Early Arab rule. In Egypt—as in Syria, Iraq, and Iran—the Arab conquerors did little in the beginning to disturb the status quo; as a small religious and ethnic minority, they thus hoped to make the occupation permanent.

Arab policies

Treaties concluded between 'Amr and the *muqawqis* (presumably a title referring to Cyrus, archbishop of Alexandria) granted protection to the native population in exchange for the payment of tribute. There was no attempt to force, or even to persuade, the Egyptians to convert to Islām; the Arabs even pledged to preserve the Christian churches. The Byzantine system of taxation, combining a tax on land with a poll tax, was maintained, though it was streamlined and centralized for the sake of efficiency. The tax was administered by Copts, who staffed the tax bureau at all but the highest levels.

To the mass of inhabitants, the conquest must have made little practical difference, because the Muslim rulers left them alone, in the beginning at least, as long as they paid their taxes; if anything, their lot may have been slightly easier, because Byzantine religious persecution had ended. Moreover, the Arabs deliberately isolated themselves from the native population, according to 'Umar's decree that no Arab could own land outside the Arabian Peninsula; this policy aimed at preventing the Arab tribal armies from dispersing and at ensuring a steady revenue from agriculture, on the assumption that the former landowners would make better farmers than would the Arab nomads.

As was their policy elsewhere, the conquerors refrained from using an established city such as Alexandria as their capital; instead, they founded a new garrison town laid out in tribal quarters. As the site for this town they chose the strategic apex of the triangle formed by the Nile Delta—at that time occupied by the Byzantine fortified township of Babylon. They named the town Fusṭāṭ, which is probably an Arabized form of the Greek term for "encampment" and gives a good indication of the nature of the earliest settlement. Like garrison towns founded by the Arabs in Iraq—Basra and Kūfah—Fusṭāṭ became the main agency of Arabization in Egypt inasmuch as it was the only town with an Arab majority and therefore required an extensive knowledge of Arabic from the native inhabitants.

The process of Arabization, however, was slow and gradual. Arabic did not displace Greek as the official language of state until 706, and there is evidence that Coptic continued to be used as a spoken language in Fusṭāṭ. Given the lack of pressure from the conquerors, the spread of their religion must have been even slower than that of their language. A mosque was built in Fusṭāṭ bearing the name of 'Amr ibn al-'Āṣ, and each quarter of the town had its own smaller mosque. 'Amr's mosque served not only as the religious centre of the town but also as the seat of certain administrative and judicial activities as well.

Although Alexandria was maintained as a port city, Fusṭāṭ, being built on the Nile bank, was itself an important port and remained so until the 14th century. 'Amr enhanced the port's commercial significance by clearing and reopening Trajan's Canal, so that shipments of grain destined for Arabia could be sent from Fusṭāṭ to the Red Sea by ship rather than by caravan.

Egypt under the caliphate. For more than 200 years—that is, throughout the Umayyad caliphate and well into the 'Abbāsid—Egypt was ruled by governors appointed by the caliphs. As a province in an empire, Egypt's status was much the same as it had been for centuries under foreign rulers whose main interest was to supply the central government with Egyptian taxes and grain. In spite of evidence that the Arab governors tried in general to collect the taxes equitably, taking into account the capacities of individual landowners to pay and the annual variations in agricultural yield, resistance to paying the taxes increased in the 8th century and sometimes erupted into rebellion in times of economic distress. Periodically, religious unrest was manifested in the form of political insurrections, especially in those exceptional times when a governor openly discriminated against the Copts by forcing them to wear distinctive clothing or, worse, by destroying their icons. Still, the official policy, especially in Umayyad times, was tolerance, partly for fiscal reasons. In order to maintain the higher tax revenues collected from non-Muslims, the Arab governors discouraged conversion to Islām and even required those who did convert to continue paying the non-Muslim tax. New Christian churches were sometimes built, and the government took an interest in the selection of patriarchs.

Resistance to taxation

More than just a source of grain and taxes, Egypt also became a base for Arab-Muslim expansion, by both land and sea. The former Byzantine shipyards in Alexandria provided the nucleus of the Egyptian navy, which between 649 and 669 joined in expeditions with the Syrian navy against Rhodes, Cyprus, and Sicily and defeated the Byzantine navy in a major battle at Phoenix in 655. By land, the Arab armies advanced both to the south and to the west. As early as 651–652 the governor of Egypt invaded Nubia and imposed a treaty that required the Nubians to pay an annual tribute and to permit the unmolested practice of Islām in the province. Raids against North Africa by Arab armies based in Egypt began in 647; by 670 the Arabs had succeeded in establishing a garrison city in Ifrīqīyah (now Tunisia), called al-Qayrawān (Kairouan), which thenceforth displaced Egypt as the base for further expansion.

While some Arabs were passing through Egypt on their way to campaign in North Africa, others were being sent to the Nile Valley on a permanent basis. In addition to tribal contingents that at times escorted newly appointed governors to Egypt (some of which settled in towns), tribesmen were sometimes imported and settled in an effort to increase the Arab-Muslim concentration in the vicinity of Fusṭāṭ. The settlement of large numbers of anarchic tribesmen in Egypt, with tribal ties and allegiances elsewhere in the empire, meant that Egypt became embroiled in po-

Civil strife

litical difficulties with the central government. Civil strife centring around the assassination of the caliph 'Uthmān (656) began in Egypt, where the tribesmen resented the favouritism shown by the caliph to members of his own family. Uprisings led by the dissident Khārijite sect (the Seceders) were frequent in the mid-8th century. In the 9th century the caliph Ma'mun himself led an army from Iraq to put down a rebellion raised both by tribesmen and by Copts; repression of the Copts accompanying their defeat in 829–830 is usually cited as an important factor in accelerating conversion to Islām.

The difficulty inherent in ruling Egypt from Baghdad, which was itself undergoing stress and turbulence, is evident from the rapid turnover in governors assigned to Egypt; the 'Abbāsid caliph Hārūn ar-Rashid (ruled 786–809), for example, appointed 24 governors in a reign of 23 years. Possibly as a means of both removing the governorship from the level of tribal strife and paying the central government's Turkish troops, the caliphs began assigning Egypt to Turks rather than to Arabs. But this policy resulted in no tangible improvement in the administration of Egyptian affairs until 868, when the reign of Aḥmad ibn Ṭūlūn inaugurated a new phase of medieval Egyptian history.

The Ṭūlūnid dynasty (868–905). Though short-lived, the Ṭūlūnid dynasty succeeded in restoring a measure of Egypt's ancient glory. For the first time since the pharaohs, Egypt became virtually autonomous and the bulk of its revenues remained within its borders. What is more, Egypt became the centre of a small empire when Ibn Ṭūlūn conquered Syria in 878–879. These developments were paralleled in other provinces of the 'Abbāsid Empire and were the direct result of the decline of the caliph's power. In order to strengthen their armies, the 'Abbāsid caliphs had begun early in the 9th century to form contingents of Turkish slaves. To finance these new military formations and, in particular, to pay the Turkish commanders who headed them, the caliphs began to give them administrative grants (*iqṭā'* in Arabic, usually translated "fief") consisting of tax revenues from certain territories. In 868 Egypt was granted as a fief to the Turkish general Babak, who chose to remain in Iraq but appointed his stepson, Aḥmad ibn Ṭūlūn, as his agent in Egypt. Ibn Ṭūlūn's great achievement was that he quickly established his own authority in Egypt and backed it up with an army of his own creation, powerful enough to defy the central government of Baghdad and to embark upon foreign expansion.

Ibn Ṭūlūn's first step was to eliminate possible rivals in Egypt. From an early date the administration of Egypt had been divided between the *amir* (military governor), appointed by the caliph, and the *'āmil* (fiscal officer), who was sometimes appointed by the caliph, sometimes by the governor. When Ibn Ṭūlūn entered Egypt in 868 he found the office of *'āmil* filled by one Ibn al-Mudabbir, who over a period of years had gained control of Egyptian finances, enriching himself in the process, and was therefore reluctant to acknowledge Ibn Ṭūlūn's authority. A struggle for power soon broke out between the two, which ended four years later with the transfer of Ibn al-Mudabbir to Syria and the assumption of his duties and powers by Ibn Ṭūlūn. An even more important step was the acquisition of an army that would be independent of the caliphate and loyal to Ibn Ṭūlūn. To build such an army, Ibn Ṭūlūn resorted to the same method the caliphs themselves used—the purchase of slaves who could be trained as military units loyal to their owner.

In 877, when Ibn Ṭūlūn failed to pay Egypt's full contribution to the 'Abbāsid campaign against a black slave uprising in Iraq, the caliphal government, dominated by the caliph's brother al-Muwaffaq, realized that Egypt was slipping from imperial control. An expedition dispatched by al-Muwaffaq to remove Ibn Ṭūlūn from the governorship failed. Taking advantage of the caliphate's preoccupation with the revolt, Ibn Ṭūlūn in 878 invaded Syria, where he occupied the principal cities and garrisoned them with his troops. Thereafter he signified his autonomy by imprinting his name on the coinage along with the name of the caliph. Although the regent al-Muwaffaq lacked the resources to engage Ibn Ṭūlūn in battle, he did have him publicly cursed in the mosques of the empire as a means of retaliation.

Autonomy under Ibn Ṭūlūn

Internally, Ibn Ṭūlūn took active measures to raise Egyptian agricultural productivity and thereby to increase tax revenues; the huge surplus he left in the state treasury at his death in 884 is a measure of his success. Another tangible indication of his achievement for Egypt is an enormous mosque (still standing) that he erected in a suburb of Fusṭāṭ; in contrast, no building comparable in grandeur had even been contemplated by the governors who preceded him.

The great benefits Ibn Ṭūlūn had gained for Egypt by using its resources within the country were squandered by his son and successor, Khumārawayh. He expended huge sums on luxurious appointments for his residence and paid a fortune as a dowry for a daughter he married to the caliph al-Mu'taḍid in 895. Nevertheless, Khumārawayh was able to maintain the Egyptian armies in the field, and he led them to victory both in Syria and in Mesopotamia. He resolved his father's conflict with the caliphate by a combination of arms and diplomacy, so that Khumārawayh's authority over Egypt, Syria, and Mesopotamia was given official caliphal recognition. This apparent strength evaporated when Khumārawayh was murdered in 896, leaving no funds with which his heir, a 14-year-old youth, could pay the troops. Both Egypt and Syria fell into anarchy, which lasted until 905 when a caliphal army invaded Egypt and momentarily restored it to the status of a province ruled by governors sent from Baghdad.

The Ikhshīdid dynasty (935–969). For 30 years the governors were unable to restore stability in Egypt. During this time, Egypt was subjected to attacks from the Fāṭimid state based in North Africa and to the rampages of an unruly domestic army. The appointment of Muḥammad ibn Ṭughj, from Sogdiana in Central Asia, as governor in 935 led to a repetition of Ibn Ṭūlūn's achievement; by bold measures Muḥammad established his authority over the treasury and the army, reasserted Egyptian influence in Syria, and won the governorship of the Holy Cities of Arabia (Mecca and Medina). In addition, he founded a dynasty; his sons inherited his Sogdian princely title of *ikhshīd*, but their authority was usurped by their Abyssinian slave tutor, Kāfūr, who ruled Egypt with the caliph's sanction. When Kāfūr died in 968 the Ikhshīdids were unable to maintain order in the army and the bureaucracy. In the following year the Fāṭimids took advantage of the disorder in Egypt to launch yet another attack, this one so successful that it led to the occupation of the country by a Berber army led by the Fāṭimid general Jawhar.

The Fāṭimid dynasty (969–1171). The establishment of the Fāṭimid caliphate in 973 in the newly built palace city of Cairo had dramatic consequences for the evolution of Islāmic Egypt. Politically, the Fāṭimids went a step further than the Ṭūlūnids by setting up Egypt as an independent rival to the 'Abbāsid caliphate. In fact, an avowed aim of the early Fāṭimid propagandists was to achieve world dominion, eradicating the 'Abbāsid caliphate in the process. For a variety of reasons they achieved neither of these goals; nevertheless, at the height of Fāṭimid power at the beginning of the 11th century, the Fāṭimid caliph could claim sovereignty over the whole North African coastal region, Sicily, the Hejaz and Yemen in Arabia, and southern Syria. Although actual political-military control was never firm except in Egypt, allegiance paid to the Fāṭimids by their provinces was just as meaningful as that paid to the 'Abbāsids and for a time was certainly more widespread. Even when the Fāṭimid state fell into decline later in the 11th century and abandoned its imperial vision, Egypt continued to play an independent role in the Islāmic world under the leadership of Armenian generals who had gained control of the Fāṭimid armies.

Egypt set up as a rival to the 'Abbāsid caliphate

Islāmization. It is difficult to estimate the religious change effected by the new dynasty except on the level of the governmental elite, which espoused the official doctrine of Ismā'īlī Shī'ism—the branch that held all authority to inhere in the line of Ismā'īl, who had predeceased both his father, the sixth 'Alid *imām* Ja'far ibn Muḥammad, and his own son, Muḥammad at-Tamm. Because they believed that the Fāṭimid caliph was the only legitimate

leader, the practice of Sunnī (orthodox) Islām was theoretically outlawed in Fāṭimid domains. But the practical difficulties which the Ismā'īlī minority faced in imposing its will on the Sunnī majority meant that the Muslim population of Egypt remained predominantly Sunnī throughout the Fāṭimid period. Certainly there was no public outcry when Saladin, who founded the Ayyūbid dynasty, restored Egypt to Sunnī rule in 1171. Regarding non-Muslims, the Fāṭimids, with one notable exception, were known for their tolerance, and the Copts continued to serve in the bureaucracy. Several Copts held the highest administrative post—the vizierate—without changing their religion. Jews also figured prominently in the government; in fact, a Jewish convert to Islām, Ibn Killis, was the first Fāṭimid vizier and is credited with laying the foundations of the Fāṭimid administrative system. Christians and Jews even managed to survive the reign of the mad caliph al-Ḥākim (ruled 996–1021), who ordered the destruction of Christian churches in Fāṭimid territory, including the Church of the Holy Sepulchre in Jerusalem, and offered his non-Muslim subjects the choice of conversion to Islām or expulsion from Fāṭimid territory. This period of persecution undoubtedly accelerated the rate of conversion to Islām, if only on a temporary and superficial level.

Lack of literature and learning

In comparison with Iraq, Egypt contributed relatively little to Arabic literature and Islāmic learning during the early 'Abbāsid period. But the Fāṭimids' intense interest in propagating Ismā'īlī Shī'ism through a network of missionary propagandists made Egypt an important religious and intellectual centre. The foundation of the mosque-college of al-Azhar as well as of other academies drew Shī'ite scholars to Egypt from all over the Muslim world and stimulated the production of original contributions in literature, philosophy, and the Islāmic sciences.

Arabization. The Arabization of Egypt continued at a gradual pace. The early Fāṭimids' reliance on Berber troops was soon balanced by the importation of Turkish, Sudanese, and Arab contingents. The Fāṭimids are said to have used thousands of nomadic Arabs in the Egyptian cavalry and to have further stimulated Arabization by settling large numbers of Arabian tribesmen in Upper Egypt to deprive the Qarmaṭians—their Ismā'īlī enemies in Iraq and Arabia—of Arab tribal support. On the other hand, the Fāṭimids reduced the Arab population of Egypt in the mid-11th century, when they incited the Banū Hilāl and the Banū Sulaym tribes to emigrate from Egypt into the neighbouring Berber kingdom of Ifrīqiyah.

Egyptian commerce

Growth of trade. One of the most far-reaching changes in Fāṭimid times was the growth of Egyptian commerce, especially in Fusṭāṭ, which had become the port city for Cairo, the Fāṭimid capital. Theretofore, Iraq in the east and Tunisia in the west had been flourishing centres for trade conducted both within the Muslim world and between the Muslim and the Christian empires of the West. A number of factors contributed to alter this situation in favour of Egypt. As centralized power declined in Iraq, Mesopotamia, and Syria during the 9th and 10th centuries, traffic on the trade routes across these areas also declined. In Egypt, however, the establishment of a strong government, which soon controlled the Red Sea and maintained a strong navy in the eastern Mediterranean, offered an attractive alternative for the international transit trade between the Orient and Christendom. In addition to having the political stability essential for trade, the Fāṭimids encouraged commerce by their low tariff policy and their noninterference in the affairs of merchants who did business in Egypt. These factors, along with increased European mercantile activity in the Italian cities, helped restore Egypt as a great international entrepôt.

The end of the Fāṭimid dynasty. The Fāṭimid achievement in restoring to Egypt a measure of its ancient glory was remarkable but brief. Halfway through their history the political-religious authority of the Fāṭimid caliphs was vitiated by military uprisings that could be put down only by force. By 1163 the Fāṭimid caliph had been shunted aside in a power struggle between the vizier and the chamberlain, who were themselves so impotent that they had to seek help from the Sunnī and even from the crusader powers of Syria and Palestine. Thus began a series of invasions at the behest of Fāṭimid officials, which ended in 1169 with the occupation of Egypt by an army from Syria, one of whose commanders—Saladin—was appointed Fāṭimid vizier. Two years later Saladin restored Egypt to 'Abbāsid allegiance, abolished the Fāṭimid caliphate, and, in effect, established the Ayyūbid dynasty.

The Ayyūbid dynasty (1171–1250). Under Saladin and his descendants, Egypt was reintegrated into the Sunnī world of the Eastern caliphate. Indeed, Egypt became champion of that world against the crusaders and, as such, chief target of the crusader armies. But this was a gradual process that required Saladin first to build an army strong enough to establish his power in Egypt and then to unite the factions of Syria and Mesopotamia under his leadership against the Franks. By so doing he reconstituted the Egyptian empire, which included, in addition to the areas just named, Yemen, the Hejaz, and, with the fall of Jerusalem (1187), a major part of the Holy Land.

Return to the Eastern caliphate under Saladin

The abolition of the Fāṭimid caliphate and the official reinstitution of Sunnī Islām seems to have caused little perturbation in Egypt except for an uprising by the Fāṭimid palace guard, quickly suppressed. This undoubtedly means that Ismā'īlī Shī'ism was confined to Fāṭimid ruling circles.

Saladin's policies. Saladin's remission of all taxes not explicitly sanctioned by Islāmic law must have contributed to his own popularity as well as to the stability of his regime. To ensure the defense of his state against both internal and external enemies, he strengthened the fortifications of Cairo by building a citadel and extending the Fāṭimid city walls. Despite the major military and propagandistic efforts mounted against the crusaders, Saladin continued to treat the Christians of Egypt with tolerance; the Coptic Church thrived under the Ayyūbids, and Copts still served the government. Saladin also treated the Christians of Jerusalem with magnanimity after the conquest of that city.

Much to the consternation of the popes, trade between Egypt and the Italian city-states remained brisk, and the Egyptians were able to use raw materials provided by the Italian merchants to forge weapons against the crusaders. The administration of Egypt stayed in the hands of the vast, mainly civilian, bureaucracy, but was supervised by military officials.

Power struggles. The Ayyūbids introduced a significant change in the governance of their empire that was decisive for the history of their rule in Egypt. Though the Ayyūbids were themselves of Kurdish descent, Saladin followed the Turkish practice of assigning the provinces as fiefdoms to members of his family. In theory, such a measure would ensure the loyalty of the provinces to the central government of Egypt through the loyalty of Ayyūbid kinsmen to their family leader. In practice, however, the measure led to recurrent power struggles in which each governor used his province as a base from which to defy the supreme Ayyūbid power of Egypt. The sultans al-Malik al-'Ādil (died 1218) and al-Malik al-Kāmil (died 1238) each succeeded in reuniting Syria and Egypt under his own leadership. Kāmil, especially, was able to exploit Frankish attacks—in the form of the Fifth Crusade, directed against Damietta—to rally family and provincial support for the defense of Egypt. Nevertheless, given the dissension within the Ayyūbid empire, it was clearly in the interest of the Egyptian sultan to reach a peaceful settlement with the crusaders; this was achieved in 1229 by a truce between Kāmil and the Holy Roman emperor Frederick II. The agreement stipulated that Kāmil exchange possession of Jerusalem and other territory in the Holy Land for Frederick's guarantee to support the sultan against aggression from any source.

Growth of Mamlūk armies. The only real security for Ayyūbid Egypt lay in its independent military strength. This explains why one of the last sultans, al-Malik aṣ-Ṣāliḥ Ayyūb (died 1249), resorted to increased purchase of Turkish slaves—called Mamlūks, a name derived from the Arabic word for slave—as a means of manning his armies. Although slave troops had formed an important part of Egyptian armies since the time of Aḥmad ibn Ṭūlūn, their strength had been checked by racial dissension

among the various slave units and by the presence of nonslave elements. But after the death of aṣ-Ṣāliḥ Ayyūb in the course of the Sixth Crusade, which the Egyptians defeated thanks to the Mamlūk corps, the Mamlūks were able to exploit a palace feud and to elevate a member of their own ranks to the sultanate. Thus was established the Mamlūk sultanate, which lasted for two and a half centuries and brought Egypt to the peak of its evolution in the medieval period.

THE MAMLŪK AND OTTOMAN PERIODS (1250–1800)

The Mamlūk dynasty (1250–1517). During the Mamlūk period Egypt became the unrivaled political, economic, and cultural centre of the eastern Arabic-speaking zone of the Muslim world. Symbolic of this development was the reestablishment in 1261 under the Mamlūks of the ʿAbbāsid caliphate in Cairo (the Mongols had abolished the caliphate when they invaded Baghdad in 1258). Although the caliph enjoyed little authority and had no power, the mere fact that the Mamlūks chose to maintain the institution in Cairo is a measure of their determination to dominate Arabic Islām. It is curious that the Mamlūks—all of whom were of non-Arab, non-Muslim origin and some of whom knew little if any Arabic—established a regime that saved a substantial portion of Muslim territory from pagan domination and established Egypt's supremacy in Arabic culture.

Egypt as the centre of eastern Islām under the Mamlūks

Political life. The political history of the Mamlūk state is complex; during their 264-year reign, no fewer than 45 Mamlūks gained the sultanate, and once, in desperate circumstances, a caliph (in 1412) was briefly installed as sultan. At times individual Mamlūks succeeded in establishing dynasties, most notably Sultan Qalāʾūn (ruled 1279–90), whose progeny ruled Egypt, with two short interruptions, until 1382. Often the Mamlūks chose to allow a sultan's son to succeed his father only for as long as it took another Mamlūk to build up enough support to seize the throne for himself. In reality there was no principle of legitimacy other than force, for without sufficient military power a sultan could expect to be overthrown by a stronger Mamlūk. (D.P.L.)

Nevertheless, several sultans succeeded in harnessing the energies of the Mamlūk system to establish internal stability and to embark on foreign conquests. Soon after the Mamlūk victory over the Mongols at ʿAyn Jālūt in 1260, Baybars I seized power. He was the true founder of the Mamlūk state, and he compaigned actively and with success against the remaining crusader possessions in Palestine and Syria. He ruled until 1277. During the long reign of al-Malik an-Nāṣir (ruled 1293–1341), the Mamlūks concluded a truce with the Mongols (1323) after several major battles and, despite widespread famine, outbreaks of religious strife, and Bedouin uprisings, maintained economic prosperity in Egypt and peaceful relations with foreign powers, both Muslim and Christian. (D.P.L./D.S.Ri.)

Although the state began to decline politically and economically after the death of Nāṣir in 1341, Egypt continued to dominate Eastern Arabdom. But the cumulative effect of the plague, which swept Egypt in 1348 and on many occasions subsequently; Timur's victory in Syria in 1400; and Egypt's loss to the Portuguese of control over the Indian trade, along with the sultans' inability to keep their refractory Mamlūk corps under control, gradually sapped the strength of the state. The best efforts of such a vigorous sultan as Qā'it Bāy (ruled 1468–96) failed to make Egypt strong enough to defend its Syrian empire against raids by the Turkoman states of Anatolia and Azerbaijan and campaigns of the Ottoman Turks.

Contributions to Arabic culture. By the time of the Mamlūks, the Arabization of Egypt must have been almost complete. Arabic had been the language of the bureaucracy since the early 8th century and the language of religion and culture even longer. Moreover, the prevalence of Arabic as a written and spoken language is attested by the discovery in the geniza (storeroom) of a Cairo synagogue of thousands of letters and documents—called the "Geniza Documents"—dating from the 11th through the 13th century. Though often written in Hebrew characters, the actual language of most of these documents is Arabic, which proves that Arabic was widely used even by non-Muslims. The main incentive for learning Arabic must have come from the desire of a subject population to learn the language of the ruling elite. The immigration of Arab tribesmen during the early centuries of the occupation, and their intermarriage with the indigenous inhabitants, must also have contributed to the gradual spread of Arabic in Egypt.

Prevalence of Arabic in Mamlūk Egypt

The specific Mamlūk contribution to Arabic culture, however, lay above all in the military achievement. By defeating the Mongols, the Mamlūks provided a haven in Syria and in Egypt for Muslims fleeing from Mongol devastation. The extent of this haven was narrowed by subsequent Mongol attacks against Syria, one of which led to a brief Mongol occupation of Damascus in 1294–95, so that Egypt received an influx of refugees from Syria itself as well as from areas farther east.

This accidental displacement of scholars and artisans into Egypt does not, however, wholly account for the efflorescence of certain types of cultural activity under the Mamlūks. In the same way as they supported the caliphate as a visible symbol of their legitimate claim to rule Islāmic territory, the Mamlūks cultivated and patronized religious leaders whose skills they needed in administering their empire and in directing the religious sentiments of the masses into safe (*i.e.*, nondisruptive) channels. Those divines who cooperated with the state were rewarded with government offices, in the case of the *ʿulamāʾ* (religious scholars), and with endowed monasteries, in the case of the Ṣūfīs (mystics). On the other hand, those who dared criticize the prevailing social and moral order were thrown into prison (such was the fate of the famous legist, Ibn Taymīyah, who, having emigrated from Mesopotamia in order to escape the Mongols, was incarcerated in Cairo by the Mamlūks and their religious functionaries for spreading seditious doctrines).

Concrete evidence of the stimulus the Mamlūks gave to cultural life can be found chiefly in the fields of architecture and historiography. Dozens of public buildings erected under Mamlūk patronage are still standing in Cairo and include mosques, colleges, hospitals, monasteries, and caravansaries. Historical writing under the Mamlūks was equally monumental, in the form of immense chronicles, biographical dictionaries, and encyclopaedias.

Religious life. The Mamlūk period is also important in Egyptian religious history. With few and therefore notable exceptions, the Muslim rulers of Egypt had seldom interfered with the lives of their Christian and Jewish subjects so long as these groups paid the special taxes levied on them in exchange for state protection. Indeed, both Copts and Jews had always served in the Muslim bureaucracy, sometimes in the very highest administrative positions. Even the Crusades apparently failed to upset the delicate balance between Muslims and Christians. Trade with the Italian city-states had certainly continued, and there is no evidence that the local Christians were held accountable for the crusader invasions of Egypt. While it is true that Saladin dismissed all Copts from the bureaucracy and imposed sumptuary laws on them, this policy was abandoned by his successors in their desire to reach an accommodation with the crusaders.

With the establishment of the Mamlūk dynasty, however, it is generally agreed that the lot of the Christians, both in Egypt and in Syria, took a distinct turn for the worse. One indication of this change is the increased production of anti-Christian polemics written by Muslim theologians. A possible reason for the change may have been the association of Christians with the Mongol peril. Because the Mongols used Christian auxiliaries in their armies—Georgians and Armenians in particular—they often spared the Christian populations of towns they conquered, while slaughtering the Muslims. Also, the diplomatic efforts aimed at uniting the Mongols with Christian European powers in a joint crusade against the Muslims might have contributed to the Mamlūks' distrust of the Christians. But the dissatisfaction seems to have originated not so much with the Mamlūk rulers as with the masses, and it seems to have been directed not so much against Chris-

Anti-Christian feelings

tians' sympathy for the Mongols as against their privileged position and role in the Mamlūk state.

On several occasions popular resentment against the Copts' conspicuous wealth and their employment in the government was manifested in public demonstrations. Both Muslims and Christians resorted to arson, burning the others' sanctuaries, to express their hatred. Under such pressure, the Mamlūk government dismissed Christians from the bureaucracy on no fewer than nine occasions between 1279 and 1447, and in 1301 it ordered all the churches in Egypt closed. As a result of these intermittent persecutions and the destruction of churches, it is believed that the rate of conversion to Islām accelerated markedly in the Mamlūk period and that Coptic virtually disappeared except as a liturgical language. By the end of the Mamlūk dynasty, the Muslims may well have reached the same numerical superiority that they enjoy in modern times—a ratio of more than 10 to one.

Economic life. In trade and commerce, the Mamlūk period marks the zenith of medieval Egyptian economic history. During the 13th and 14th centuries (as long, that is, as the sultanate was able to maintain order in Egypt), trade was heavy with Mediterranean and Black Sea ports and with India. The Oriental trade was controlled largely by a group of Muslim merchants known as the Kārimīs; the Mediterranean trade was left to European traders, whom the Mamlūks allowed certain privileges in Alexandria. By the 15th century, however, Egypt's commercial importance rapidly deteriorated as the result of population losses, increased government interference in commerce, Bedouin raiding, and Portuguese competition in the Indian trade.

The Ottomans (1517–1798). With the Ottomans' defeat of the Mamlūks in 1516–17, Egyptian medieval history had come full circle, as Egypt reverted to the status of a province governed from Istanbul. Again the country was exploited as a source of taxation for the benefit of an imperial government and as a base for foreign expansion. The economic decline that had begun under the late Mamlūks continued, and with it came a decline in Egyptian culture.

Economic decline under Mamlūks

Some historians attribute the lethargy of Ottoman Egypt solely to Ottoman domination. But although Ottoman policy was geared to imperial, not Egyptian, needs, it was obviously to the rulers' benefit to provide a stable government that would maintain Egyptian agriculture at a high level of productivity and would promote the transit trade. To a certain extent Ottoman actions served these purposes. The decisive factor that ultimately undermined Ottoman policies was the perpetuation of the former Mamlūk elite; though they collaborated with the Ottoman government, they often defied it and in the end they dominated it. By and large the history of Ottoman Egypt concerns the process by which the conquered Mamlūks reasserted their power within the Egyptian state.

The Ottoman conquest. From the conquest itself, the Ottoman presence in Egypt was entangled with Mamlūk factionalism. There is no doubt that the Ottomans invaded Syria in 1516 to break an incipient coalition against Ottoman expansion between the Ṣafavids of Persia and the Mamlūks of Egypt and Syria. The long-standing enmity between the Ottomans and the Mamlūks arose from their contest to control the Turkoman frontier states north of Syria. After the Ottomans strengthened their hold over eastern Anatolia in 1514, it was only natural that the Mamlūks should attempt to bolster their forces in northern Syria and exchange diplomatic missions with the Ṣafavids. The Ottoman sultan Selim the Grim responded by attacking the reinforced Mamlūk army in Syria, probably as a preliminary step in a new campaign against the Ṣafavids. In 1516, after Selim had defeated the Mamlūks at Marj Dābiq (north of Aleppo), Ottoman goals had probably been met, especially since the Mamlūk sultan Qānṣūh al-Ghauri died in the battle. But the Mamlūks rallied around a new sultan in Cairo, who refused to accept Selim's terms for a settlement. Spurred on by the Mamlūk traitor Khair Bey, Selim marched against Egypt in 1517, defeated the Mamlūks, and installed Khair Bey as Ottoman governor. Khair Bey died in 1552; thereafter, the Ottoman viceroy (called *vali*), with the title of pasha, was sent from Istanbul.

Mamlūk factionalism

Ottoman administration. In 1525 the Ottoman administration of Egypt was defined and codified by the Ottoman grand vizier, Ibrahim Paşa, who was dispatched to Egypt for this purpose by the sultan Süleyman the Magnificent. According to the terms of Ibrahim Paşa's decree (*qanunname*), Egypt was to be ruled by a viceroy aided by an advisory council (divan) and an army comprising both Ottoman and local corps. The collection of taxes and the administration of the four provinces into which Egypt was divided were assigned to inspectors (*kashifs*). Although the Egyptian government was headed by bureaucratic officials sent from Istanbul, and supported by Ottoman troops, the Mamlūks were able to penetrate both the bureaucracy and the army. The *kashifs* were often drawn from Mamlūk ranks; three of the seven military corps formed by the Ottomans in the 16th century were recruited in Egypt, one of which—the Circassians—was composed of Circassian Mamlūks. Their service in the army enabled the Mamlūk amirs to secure high-ranking military posts that entitled them to serve on the divan itself.

By the 17th century a distinct elite bearing the title of bey had emerged, which consisted largely of Mamlūk amirs. These beys held no specific offices but were nevertheless paid a salary by the Ottoman government. The elite was perpetuated through the old Mamlūk system of purchasing slaves, giving them military training, then freeing them and attaching them to one of the great Mamlūk houses of Egypt. Thus, for all practical purposes, the Mamlūks maintained themselves as an elite throughout the Ottoman period. They were no longer the only political-military elite, as they had been in the past, but they ultimately succeeded in reestablishing their dominance. Yet the chief obstacle to the growth of their power was not so much the Ottoman ruling hierarchy as it was their own factionalism. During the 17th and 18th centuries the Mamlūks were divided into two great rival houses—the Faqariyya and the Qasimiyya—whose mutual hostility often broke out into fighting and impaired the strength of Mamlūks as a bloc.

The beys

Mamlūk power under the Ottomans. In spite of internal dissension and the resistance of the non-Mamlūk hierarchy, the Mamlūks had emerged by the early 18th century as the supreme power in Egyptian politics. While the beys continued to acknowledge the authority of the Ottoman viceroy and to send tribute to Istanbul, the strongest single figure in Egypt was the bey who held the newly coined title of *shaykh al-balad* ("chief of the city"), which signified that he was recognized by the other beys as their chief. The Mamlūks' rise to power was climaxed by the careers of two amirs—'Alī Bey and Abū Dhahab—both of whom secured from the Sublime Porte (Ottoman government) de facto recognition of their autonomy in Egypt (1768–76) and even undertook military campaigns in Syria and the Hejaz. The Ottomans attempted to end the Mamlūk domination by sending an army to Egypt in 1786. Although it was initially successful, this attempt failed and the troops were withdrawn a year later. A Mamlūk duumvirate was reestablished, and it lasted until Napoleon invaded Egypt in 1798.

Expansion. During the 16th century, when their regime in Egypt was strongest, the Ottomans used Egypt as a base for expansion to the south. Like the Mamlūk rulers before them, they attempted to control the southern approaches to Egypt by instituting their authority in Nubia; this they achieved by annexing Nubia as far south as the Third Cataract. Elsewhere, they undertook to reassert Egyptian command of the Red Sea, which the Portuguese had begun to contest during the early 16th century. Ottoman fleets and troops captured Yemen and Aden (1536–46) and thus dominated the lower Red Sea; in 1557 they strengthened this position by setting up a colony on the Abyssinian coast at Mitsiwa (Massawa). In the 17th century these outposts began to lose their importance as Ottoman and Portuguese power began to decline and the Dutch took over the spice trade.

Culture. Given the political instability and the economic decline that had prevailed in Egypt since late Mamlūk times, it is not surprising that the culture of Ottoman Egypt lacked vitality. Perhaps the most telling example of intellectual quiescence was the dramatic decline in the

Impact of political instability

quantity of historical works produced in Egypt. As already noted, the Mamlūk period is renowned for the number and quality of its historians, partly because the amirs patronized court historians; by contrast, in almost three centuries of Ottoman rule Egypt produced only one historian worthy of note, al-Jabartī (died 1825), famous for his observations on the French occupation. The Ottomans also fell short of the Mamlūks' achievement in architecture; there is no lack of public buildings erected under Ottoman patronage, but even the best of these are imitations of the Byzantine basilica, which had been adopted as the model for mosques.

Religious affairs. Like all previous Muslim governments, the Ottomans continued to employ Copts in the financial offices of the bureaucracy. The Ottomans allowed the caliphate, so assiduously preserved in its nominal form by the Mamlūks, to lapse. At first the caliph was installed in Istanbul by Selim the Grim. Later the caliph—the last of the 'Abbāsid line—returned to Egypt, where he died in the reign of Süleyman. The claim that the caliph had transferred his authority to the Ottoman sultan is an 18th-century invention. (D.P.L.)

FROM THE FRENCH TO THE BRITISH OCCUPATION (1798–1882)

The French occupation and its consequences (1798–1805). Although several projects for a French occupation of Egypt had been advanced in the 17th and 18th centuries, the purpose of the expedition that sailed under Napoleon Bonaparte from Toulon in May 1798 was specifically connected with the war against Britain. Bonaparte had discounted the feasibility of an invasion of England but hoped, by occupying Egypt, to damage British trade, to threaten India, and to obtain assets for bargaining in any future peace settlement. Meanwhile, as a colony under the benevolent and progressive administration of Revolutionary France, Egypt would be regenerated and regain its ancient prosperity. The military and naval forces were therefore accompanied by a commission of scholars and scientists to investigate and report the past and present condition of the country.

Eluding the British Mediterranean fleet under Lord Nelson, the French landed at Abū Qīr (Aboukir) Bay on July 1 and took Alexandria the next day. In an Arabic proclamation, Bonaparte assured the Egyptians that he came as a friend to Islām and the Ottoman sultan, to punish the usurping Mamlūks and to liberate the people. From Alexandria the French advanced on Cairo, defeating Murad Bey at Shubrākhīt (July 13), and again decisively at Imbābah, opposite Cairo in the so-called Battle of the Pyramids on July 21. Murad fled to Upper Egypt, while his colleague, Ibrāhīm Bey, together with the Ottoman viceroy, made his way to Syria.

Battle of the Pyramids

After entering Cairo (July 25), Bonaparte sought to conciliate the population, especially the religious leaders (*'ulamā'*), by demonstrating his sympathy with Islām and by establishing councils (divans) as a means of consulting Egyptian opinion. The destruction of the French fleet at Abū Qīr by Nelson in the so-called Battle of the Nile on August 1 virtually cut Bonaparte's communications and made it necessary for him to consolidate his rule and to make the expeditionary force as self-sufficient as possible. The savants, organized in the Institut d'Égypte, played their part in this. Meanwhile, Egyptian resentment at alien rule, administrative innovations, and the growing fiscal burden of military occupation was exacerbated when the Ottoman sultan, Selim III (1789–1807), declared war on France on September 11. An unforeseen revolt in Cairo on October 21 was suppressed after an artillery bombardment that ended any hopes of cordial Franco-Egyptian coexistence.

Ottoman Syria, dominated by Aḥmad al-Jazzār, the governor of Acre, was the base from which French-occupied Egypt might most easily be threatened, and Bonaparte resolved to deny it to his enemies. His invasion force crossed the frontier in February 1799 but failed to take Acre after a protracted siege (March 19–May 20), and Bonaparte evacuated Syrian territory. A seaborne Ottoman invading force landed at Abū Qīr in July but failed to maintain its bridgehead. At this point Bonaparte resolved to return to France and succeeded in slipping away on August 22, past the British fleet.

His successor as general in chief, Jean-Baptiste Klēber, viewed the situation of the expeditionary force with pessimism and, like many of the soldiers, wished to return to the theatre of war in Europe. He therefore entered into negotiations with the Ottomans and by the Convention of al-'Arīsh (Jan. 24, 1800) agreed to evacuate Egypt. Sir Sydney Smith, the British naval commander in the eastern Mediterranean, sponsored the convention, but in this he had exceeded his powers and was instructed by his superior officer, Admiral Lord Keith, to require the French to surrender as prisoners of war. Although the Ottoman reoccupation was well underway, Klēber and the French determined on resistance and defeated the Turkish forces at the Battle of Heliopolis (March 20). A second revolt of Cairo, fomented by Ottoman fugitives, took about a month to suppress; but French authority had been restored when Kléber was assassinated by a Syrian Muslim, Sulaymān al-Ḥalabī, on June 14.

His successor, 'Abd Allāh Jacques Menou, a French officer (and former nobleman) who had turned Muslim, was determined to maintain the occupation and administered at first a tolerably settled country, although he lacked the prestige of his two predecessors. In 1801 a threefold invasion of Egypt began. British troops were landed at Abū Qīr in March, while the Ottomans advanced from Syria. Shortly afterward, British Indian forces were landed at Quṣayr on the Red Sea coast. The French garrison in Cairo capitulated in June and Menou himself at Alexandria in September.

Surrender of the French

The brief episode of the French occupation was to be significant for Egypt in several ways. The arrival of a European army accompanied by scholars and scientists appropriately inaugurated the impact of the West, which was to be felt increasingly in the next 150 years. Egypt, protected for five centuries by the Mamlūk and Ottoman sultanates, was no longer immune from European attack: it had become an object of the contending policies of France and Britain, a part of the "Eastern Question." Bonaparte's savants had little success in interpreting Western culture to the traditionalist *'ulamā'* of Cairo; their achievement was rather to unveil Egypt to Europe. They uncovered the celebrated Rosetta Stone, which held a trilingual inscription making it possible to decipher hieroglyphs and which thus laid the foundation of modern Egyptology. Their reports and monographs were collected in the monumental *Description de l'Égypte* ("Description of Egypt"), which was published in parts from 1809 to 1828 in Paris.

Of more immediate consequence for Egypt was the effect of the French occupation upon internal politics. The Mamlūk ascendancy was fatally weakened. Murad Bey, who had made his peace with the French, died shortly before their capitulation in 1801; and Ibrāhīm Bey, who returned to Egypt with the Ottomans, had henceforward little power. The new Mamlūk leaders, 'Uthmān Bey al-Bardīsī and Muḥammad Bey al-Alfī, former retainers of Murad, headed rival factions and had in any case to reckon with the British and Ottoman occupation forces. In March 1803 the British were evacuated in accordance with the Peace of Amiens. But the Ottomans, determined to reassert their control over Egypt, remained, establishing their power through a viceroy and an occupying army, in which the most effective fighting force was an Albanian contingent. The Albanians, however, acted as an independent party and in May 1803 mutinied and installed their own leader as acting viceroy. When he was assassinated shortly afterward, the command of the Albanians passed to his lieutenant, Muḥammad 'Alī (born 1769), who, during the ensuing two years, cautiously strengthened his own position at the expense of both the Mamlūks and the Ottomans.

Ottomans remain in Egypt

Muḥammad 'Alī and his successors (1805–82). In May 1805 a revolt broke out in Cairo against the Ottoman viceroy, Khūrshīd Pasha. The *'ulamā'* invested Muḥammad 'Alī as viceroy. For some weeks there was street fighting, and Khūrshīd was besieged in the Citadel. In July Sultan Selim III confirmed Muḥammad 'Alī in office and the revolt ended.

Muḥammad ʿAlī's viceroyalty was marked by a series of military successes, some of which were attended by political failures that frustrated his wider aims. After the renewal of war between Britain and Napoleonic France in 1803, Egypt again became an area of strategic significance. A British expedition occupied Alexandria in 1807 but failed to capture Rosetta and, after a defeat at the hands of Muḥammad ʿAlī's forces, was allowed to withdraw.

Military expansion. In Arabia, the domination of Mecca and Medina by puritanical Wahhābi Muslims was a serious embarrassment to the Ottoman sultan, who was the titular overlord of the Arabian territory of the Hejaz and the leading Muslim sovereign. At the invitation of Sultan Mahmud II (1808–39), Muḥammad ʿAlī sent an expedition to Arabia that between 1811 and 1813 expelled the Wahhābīs from the Hejaz. In a further campaign (1816–18), Ibrāhīm Pasha, the viceroy's eldest son, defeated the Wahhābīs in their homeland of Najd and brought central Arabia within Egyptian control. In 1820–21 Muḥammad ʿAlī sent an expedition up the Nile and conquered much of what is now the northern Sudan. By so doing, he made himself master of one of the principal channels of the slave trade and began an African empire that was to be expanded under his successors.

After the outbreak of the Greek insurrection against Ottoman rule, Muḥammad ʿAlī, at Sultan Mahmud II's request, suppressed the Cretan revolt in 1822. In 1825 Ibrāhīm began a victorious campaign in the Morea in southern Greece, where his military success provoked intervention by the European powers and brought on the destruction of the Ottoman and Egyptian fleets at the Battle of Navarino in October 1827. The Morea was evacuated the following year.

Muḥammad ʿAlī's invasion of Syria

In 1831 Muḥammad ʿAlī embarked upon the invasion of Syria. His pretext was a quarrel with the governor of Acre, but deeper considerations were involved, particularly the growing strength of the Sultan, which might threaten his own autonomy. Syria, moreover, was strategically important; and its products, especially timber, usefully complemented the Egyptian economy. The Ottoman army was defeated near Konya in Anatolia (December 1832), and in 1833 the Sultan ceded the Syrian provinces to Muḥammad ʿAlī.

In 1839 Ottoman forces reentered Syria but were defeated by Ibrāhim at the Battle of Nizip (Nezib). A fortnight later Mahmud II died, and the Ottoman Empire seemed on the verge of dissolution; it was saved only by European intervention. In 1840 Ibrāhim was compelled to evacuate Syria. Muḥammad ʿAlī's Arabian empire (which since 1833 had extended into the Yemen) crumbled at the same time. Although in June 1841 the new sultan, Abdülmecid I (1839–61), conferred on the family of Muḥammad ʿAlī the hereditary rule of Egypt, the viceroy's powers were declining. Because of his growing senility, Ibrāhīm succeeded him (July 1848) but his reign lasted only a few months until his death the following November. The next viceroy was ʿAbbās I, the eldest grandson of Muḥammad ʿAlī. The old viceroy himself died in 1849.

Administrative changes. Muḥammad ʿAlī's military exploits would not have been possible but for radical changes in the administration of Egypt itself. Muḥammad ʿAlī was a pragmatic statesman whose principal object was to secure himself and his family in the unchallenged possession of Egypt. His immediate problem on his accession was to deal with the Mamlūks, who still dominated much of the country, and the *ʿulamāʾ*, who had helped him to power. The strength of these two groups rested largely on their control of the agricultural land of Egypt and the revenues arising therefrom. Gradually, between 1805 and 1815, Muḥammad ʿAlī eroded the system of tax farming that had diverted most of the revenues to the Mamlūks and other notables, imposed the direct levy of taxes, expropriated the landholders, and carried out a new tax survey. In 1809 he defeated the *ʿulamāʾ*, and in 1811 he massacred many of the Mamlūk leaders in Cairo, while Ibrāhīm expelled their survivors from Upper Egypt.

Restructuring of taxation

Muḥammad ʿAlī thus became effectively the sole landholder, with a monopoly over trade in crops, in Egypt, although later in his reign he made considerable grants of land to his family and dependents. The monopoly system was extended in due course from primary materials to manufactures, with the establishment of state control over the textile industry. Muḥammad ʿAlī's ambitious hopes of promoting an industrial revolution in Egypt were not realized, fundamentally because of the lack of available sources of power. The monopolies were resented by European merchants in Egypt and clashed with the economic doctrine of free trade upheld by the British government. Although a free-trade convention that was concluded between Britain and the Ottoman Empire in 1838 (the Convention of Balta Liman) was technically binding on Egypt, Muḥammad ʿAlī succeeded in evading its application up to and even after the reversal of his fortunes in 1840–41.

The old-style military forces (including the Albanians), on whom Muḥammad ʿAlī relied against his internal opponents and who conquered the Hejaz, Najd, and the northern Sudan, were heterogeneous and unruly. An attempt to introduce Western methods of training in 1815 provoked a mutiny. Muḥammad ʿAlī then decided to form an army of slave-troops dependent wholly upon himself and trained by European instructors. The conquest of the Sudan was intended to provide the recruits. But the slaves, encamped at Aswān, died wholesale, and Muḥammad ʿAlī had to look elsewhere for the mass of his troops. In 1823 he took the momentous step of conscripting Egyptian peasants for the rank and file of his "new model army." On the other hand, the officers were mostly Turkish-speaking Ottomans, while the director of the whole enterprise, Sulaymān Pasha (Colonel Sève), was a former French officer. The conscription was brutally administered and military life harsh. There were several ineffective peasant revolts, while flight to the towns and (before 1831) to Syria produced rural depopulation and a decline in cultivation.

Reform of the military

As reorganization proceeded, the viceroy gradually built a new administrative structure. While institutions were created and discarded according to his changing needs, Muḥammad ʿAlī depended essentially upon the members of his own family, particularly Ibrāhīm, and loyal servants, such as his Armenian confidant Boghos Bey. Characteristic of his governmental system were councils of officials, convened to deliberate on public business, and administrative departments (divans) that bore some resemblance to the ministries of European governments. In local administration, Muḥammad ʿAlī established a highly centralized system with a clear chain of command from Cairo through the provincial governors, down to the village headmen. Initiative was not encouraged, but firm control had taken the place of anarchy.

These changes necessitated the training of officers and officials in the new Europeanized ways of working; and this in turn resulted in the creation of a range of educational institutions alongside the traditional Muslim schools that prepared the *ʿulamāʾ*. Much of the foundation work was done by expatriates, while missions of Egyptian students were sent to Europe, especially to Paris. One of these, Rifāʿah Rāfiʿ aṭ-Ṭahṭāwī (1801–73), played the leading part in inaugurating the translation of European works into Arabic and so was a pioneer both in the interpretation of European culture to Egypt and in the renaissance of literary Arabic. The establishment of a government printing press in 1815 soon made possible the wide dissemination of the new books.

ʿAbbās I and Saʿīd, 1848–63. The reign of ʿAbbās I (1848–54) indicates how precarious was the advance of westernization in Egypt. The effort had already been relaxed in the last decade of Muḥammad ʿAlī's rule, and ʿAbbās showed himself to be a traditionalist. It was typical of his policy that he closed the school of languages and the translation bureau and sent their director, aṭ-Ṭahṭāwī, to virtual exile in the Sudan. The French, who had played so large a part in Muḥammad ʿAlī's reforms, fell into disfavour, and for diplomatic support ʿAbbās turned to their British rivals, whose support was needed against the Ottomans. Although initially ʿAbbās was ostentatiously loyal to the Sultan, he resented an attempt made at this time to curtail his autonomy. The British, for their part, had their communications with India facilitated by the

grant of a concession to build a railway from Alexandria to Cairo: the line was completed between 1851 and 1856 and was extended to Suez two years later. Sa'īd (1854–63), who succeeded on 'Abbās' mysterious and violent death, inaugurated another reversal of policy. While he lacked Muḥammad 'Alī's energy and ability, he was not unsympathetic to the westernizers. To his French friend Ferdinand de Lesseps (who had been a friend to Muḥammad 'Alī as well) he granted in 1854 a concession for the cutting of a canal across the isthmus of Suez. This embroiled him both with the Sultan, whose prerogative had been encroached upon, and the British, whose overland railway route was threatened by the project; a deadlock lasted throughout his reign.

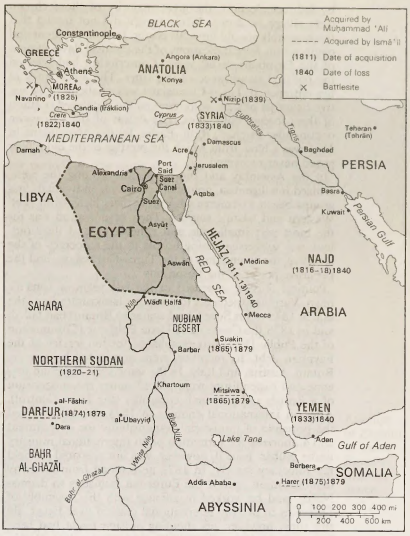
The concession to Ferdinand de Lesseps

Ismā'īl, 1863–79. Ismā'īl, the son of Ibrāhīm Pasha, who succeeded on the death of Sa'īd, displayed some of his grandfather's dynamic energy and enthusiasm for modernization. He lacked caution, however, and his reign ended in catastrophe. From his predecessors he inherited a precarious economy and a burden of debt. The American Civil War (1861–65) produced a boom in Egyptian long-staple cotton. This had been introduced and developed in Muḥammad 'Alī's time, but its production had languished until the interruption of supplies of American cotton caused a fourfold increase in price during the war years. When peace returned, prices collapsed with disastrous consequences for the Egyptian economy. In the management of his finances, Ismā'īl was both extravagant and unwise and laid himself open to unscrupulous exploitation. Ismā'īl was committed to the Suez Canal project, but he modified the grant in two important respects: by withdrawing the cession of a strip of land from the Nile to the Suez isthmus, along which a freshwater canal was to be constructed, and by refusing to provide unlimited peasant labour for the project. The matter was submitted to arbitration; an indemnity of more than £3,000,000 was imposed on Ismā'īl, who also agreed to pay for a large block of shares put by de Lesseps to Sa'id's account. French pressure on the Sultan succeeded at last in overcoming resistance to the canal project at Istanbul, and a firman (decree from the sultan) authorizing its construction was granted in March 1866. Work had in fact already been going on for seven years, and in November 1869 the Suez Canal was opened to shipping by the empress Eugénie, the wife of Napoleon III of France. The incident symbolized the political and cultural orientation of Egypt in the middle decades of the 19th century.

Ismā'īl, in other ways, presented himself as the ruler of a new and important state. Although his relations with his suzerain, Sultan Abdülaziz (1861–76), were normally friendly, he was no less anxious than his predecessors to secure the autonomy of his dynasty. In 1866 he obtained a firman establishing the succession by primogeniture in his own line—abandoning the contemporary Ottoman rule of succession by the eldest male. A year later a firman conferred upon Ismā'īl the special title of khedive, which had in fact been used unofficially since Muḥammad 'Alī's time and which distinguished the viceroy of Egypt from other Ottoman governors. A period of strained relations developed between the Khedive and the Sultan arising from Ismā'īl's implied pretensions to sovereignty at the time of the opening of the Suez Canal in 1869, but the two were later reconciled; a firman reconfirmed the Khedive's privileges in 1873. These concessions by the Sultan, however, cost Ismā'īl heavy expenditure and an increase in the annual Egyptian tribute and formed another factor in the growth of Ismā'īl's indebtedness.

Ismā'īl had inherited an African empire in the northern Sudan. Since the middle of the century, in consequence of the abolition of the monopolies, merchants had penetrated south and southwest, up the White Nile and the Baḥr al-Ghazāl, in search of ivory. An ancillary slave trade had developed that was repugnant to the European conscience. Humanitarian and expansionist motives thus coincided to persuade Ismā'īl to extend Egyptian rule into these remoter regions. He made considerable use of expatriates, notably the Englishmen Sir Samuel Baker and Charles George ("Chinese") Gordon, who extended the Khedive's nominal authority to the African Great Lakes.

Penetration southward



Expansion of Egypt under Muḥammad 'Alī and Ismā'īl.

Another series of events led to the conquest in 1874 of the sultanate of Darfur in the west. The Khedive also wished to make Egypt the dominant power in the Red Sea region. The Sultan granted him the old Ottoman ports of Suakin and Mitsiwa in 1865. Egyptian control was established on the Somali coast, and in 1875 Harer was captured. Attempts to invade Abyssinia in 1875 and 1876 were, however, unsuccessful and marked the limits of Ismā'īl's imperial expansion.

Like other parts of the Ottoman Empire, Egypt was bound by the Capitulations—a system of privileges derived from ancient treaties with former sultans. Under the Capitulations, European and American residents in Egypt were exempt from local taxation and were subject only to their own consular courts. By patient negotiations over several years, Nūbār Pasa, Ismā'īl's Armenian minister, succeeded in establishing the Mixed Courts in 1875. These had jurisdiction in cases involving Egyptians and foreigners, or foreigners of different nationalities, and had both foreign and Egyptian judges, who administered codes based on French law.

By this time the social consequences of the agrarian and political changes inaugurated by Muḥammad 'Alī were clearly appearing. The Khedive and his family were the principal landholders in Egypt, possessing extensive personal estates quite apart from the state lands. Around the khedivial family was a parvenu aristocracy that held the principal civil and military offices. Many of its members were also great landowners; most of them were Turkish or Circassian by origin. Although the condition of the peasantry had been adversely affected by military conscription, by corvées for public works (including large-scale demands for labour on the railways and the Suez Canal), and by ill-considered economic and industrial experiments, the rights of cultivators on their land gradually increased. The richer peasants, from whom the village headmen were recruited, in particular increased in importance. When in November 1866 Ismā'īl set up the consultative council known as the Assembly of Delegates, the members of which were chosen

Creation of the Assembly of Delegates

by indirect election, the great majority of those chosen were village headmen. While Ismā'īl did not intend that the Assembly should limit his power, its establishment and composition were indications of the political development of the Egyptians in 60 years. Conscription had affected the political significance of the army. The ascendancy of the entrenched Turco-Circassians was challenged by native Egyptian officers, who resented the privileged position of their foreign colleagues. The defeat of the Circassian commander in chief, Rātib Pasha, by the Abyssinians in 1876 was a blow from which the prestige of the old officer group never recovered.

In the Assembly and the army, and among the westernized intelligentsia, politically conscious individuals and groups began to emerge who drew their ideas from both Western and Islāmic sources. Their organization was for the most part small-scale and ephemeral, and their outlook was subversive, being hostile to the autocracy of the Khedive, the ascendancy of the Turco-Circassians, and the pervasive power of the Europeans.

Political tension increased in the last years of Ismā'īl's reign. Various expedients to postpone bankruptcy (*e.g.*, the sale in 1875 of his Suez Canal shares to Britain) had failed, and in 1876 the Caisse de la Dette Publique (Commission of the Public Debt) was established for the service of the Egyptian debt. Its members were nominated by France, Britain, Austria, and Italy. In the same year, Egyptian revenue and expenditure were placed under the supervision of a British and a French controller (the Dual Control). After an international enquiry in 1878, Ismā'īl accepted the principle of ministerial responsibility for government and authorized the formation of an international ministry under Nūbār. Ismā'īl, however, was not prepared to yield his autocracy tamely. In 1879 he profited from an army demonstration against the European ministers to dismiss Nūbār, and he worked in alliance with the Assembly of Delegates to destroy international control over Egypt. By this time, however, his standing outside Eygpt had been lost; and in June 1879, Sultan Abdülhamid II (1876–1908), at the instigation of France and Britain, deposed him in favour of his son, Tawfiq.

Renewed European intervention, 1879–82. European domination was immediately reasserted. The Dual Control was revived, the British controller being Evelyn Baring. By the Law of Liquidation (July 1880), the annual revenues were divided into two approximately equal portions, one of which was assigned to the Caisse de la Dette. The Assembly of Delegates was dissolved. The forces of resistance that Ismā'īl had stimulated were not, however, allayed by these means. There had already come into existence a nationalist group within the Assembly, prominent among whom was Sharif (Cherif) Pasha, prime minister from April to August 1879. In the army a group of Egyptian officers, whose leader was 'Urābī (Arabi) Pasha, was disaffected from the Khedive and resentful of European control of Egypt. By 1881 these two groups had allied to form the National Party, al-Ḥizb al-Waṭani.

Open tension appeared with a petition drawn up in January 1881 by 'Urābī and two of his colleagues against the war minister, Rifqī Pasha, a Circassian. They were arrested and court-martialed but released by mutineers. Tawfiq capitulated, dismissed Rifqī, and appointed Bārūdī Pasha, one of 'Urābī's friends, as war minister. But the 'Urābists still felt themselves endangered; a military demonstration in Cairo in September 1881 compelled Tawfiq to appoint a new ministry under Sharif and to convoke the Assembly. But the alliance between the military group and Sharif was uneasy.

European intervention

Meanwhile, the European powers were becoming increasingly alarmed. A joint English and French communication sent in January 1882 with the intention of strengthening the Khedive against his opponents had the contrary effect. The Assembly of Delegates swung toward the 'Urābists. Sharif resigned and Bārūdī became prime minister with 'Urābī as war minister. Rioting ensued on June 11 after British and French naval forces had been sent to Alexandria. From this point Britain took the initiative. The French refused participation in a bombardment of Alexandria (July 11), while an international conference held at Istanbul was boycotted by the Turks and produced no solution of the problem. The British government finally resolved on intervention and sent an expeditionary force to the Suez Canal. The 'Urābists were rapidly defeated at Tall al-Kabīr (Sept. 13, 1882), and Cairo was occupied the next day.

THE PERIOD OF BRITISH DOMINATION (1882–1952)

The British occupation and the Protectorate (1882–1922). The British occupation marked the culmination of developments that had been at work since 1798: the de facto separation of Egypt from the Ottoman Empire, the attempt of European powers to influence or control the country, and the rivalry of France and Britain for ascendancy in the country. Through the last minute withdrawal of the French, the British had secured the sole domination of Egypt. W.E. Gladstone's Liberal government was, however, reluctant to prolong the occupation or to establish formal political control, which it feared would antagonize both the Sultan and the other European powers; but the British were unwilling to evacuate Egypt without securing their strategic interests, and this never seemed possible without maintaining a military presence there.

Public trial of 'Urābī

An incident at the outset of the occupation was significant of future tensions. On British insistence, the Khedive's government was obliged to place 'Urābī and his associates on public trial and to commute the resulting death sentences to exile. Tawfiq's prestige, slight enough at his accession, and diminished in the three years before the occupation, was still further undermined by this intervention of the British government. Meanwhile, Lord Dufferin, the British ambassador in Istanbul, visited Egypt and prepared a report on measures to be taken for the reconstruction of the administrative system. The projects of reform that he envisaged would necessitate an indefinite continuation of the occupation. The implications of this for British policy were slowly and reluctantly accepted by the ministry in London, under pressure from its representative in Cairo, the British agent and consul general, Sir Evelyn Baring, who in 1891 became Lord Cromer.

Two principal problems confronted the occupying power: first, the acquisition of some degree of international recognition for its special but ambiguous position in Egypt; second, a definition of its relationship to the khedivial government, which formed the official administration of the country. The main European opponents of recognition of the British position were the French, who resented the abolition of the Dual Control (December 1882). The Caisse de la Dette remained in existence, and until 1904 the British had to tread warily in order to circumvent French opposition in this institution. In the early years of the occupation, when Egyptian finances were in disarray, French hostility was a serious problem, but from 1889 onward there was a budget surplus and consequently greater freedom of action for the Egyptian government. A moderate degree of international agreement over Egypt was attained by the Convention of London (1885), which secured an international loan for the Egyptian government and added two further members (nominated by Germany and Russia) to the Caisse de la Dette. In 1888 the Convention of Constantinople (Istanbul) provided that the Suez Canal should always be open in war and peace alike. This was, however, a statement of principle rather than fact; without British cooperation it remained a dead letter.

Cromer's personal rule

In matters concerning the international status of Egypt, the decisions were taken in London, but where the internal administration of the country was concerned, Cromer's opinions were usually conclusive. Although throughout the occupation the facade of khedivial government was retained, British advisers attached to the various ministries were more influential than their ministers, while Cromer himself steadily increased his control over the whole administrative machine. (P.M.Ho.)

Tawfiq himself gave little trouble, but his prime ministers were more tenacious. Sharif Pasha, prime minister at the beginning of the occupation until 1884, and his successors Nubar Pasha (1884–88) and Riyāḍ (Riaz) Pasha (1888–91) resigned because of clashes over administrative control. Thereafter, until November 1908, with a break in 1893–

95, the prime minister was Muṣṭafā Fahmī Pasha, who showed himself an obedient instrument of Cromer.

'Abbās Ḥilmī II, 1892–1914. The death of Tawfīq and the accession of his 17-year-old son, 'Abbās Ḥilmī II, in 1892 marked the beginning of a new phase of opposition to the occupation. The new khedive was not content to accept Cromer's tutelage, while the British agent resented the attempts of one so much his junior to play a serious role in Egyptian politics. 'Abbās dismissed Muṣṭafā Fahmī in January 1893 and tried to appoint his own nominee as prime minister. Cromer, backed by the British government, frustrated his endeavours, and Fahmī returned to office in November 1895. 'Abbās provoked another crisis in January 1894 by public criticism of British military officers and especially H.H. Kitchener, the sirdar (commander in chief). Once again Cromer intervened, and 'Abbās was compelled to make amends.

Other considerations apart, the behaviour of 'Abbās in the early years of his reign indicated the emergence of a new generation who had only been children when the occupation began. One of 'Abbās' contemporaries was Muṣṭafā Kāmil (1874–1908), who had studied in France and then had entered a circle of Anglophobe writers and politicians. On returning to Egypt in 1894 he had reached an understanding with the Khedive on the basis of their common detestation of the British occupation. By his speeches and writings (in 1900 he founded his own newspaper, *al-Liwā*), he endeavoured to create an Egyptian patriotism that would rally the entire nation around the Khedive. A boost was given to nationalism by the campaigns for the reconquest of the Sudan (1896–98) and still more by the Condominium Agreement of 1899, which nominally gave Egypt and Britain joint responsibility for the administration of the reconquered territory but in effect made the Sudan a British possession.

Muṣṭafā Kāmil

A final episode in the reconquest of the Sudan, the confrontation of British and French at Fashoda on the White Nile in 1898, was followed by the reconciliation of the two powers in the Entente Cordiale (1904), which in effect gave Britain a free hand in Egypt. This was a blow to the hopes of Muṣṭafā Kāmil and to his alliance with the Khedive, who showed himself more willing to cooperate with Cromer. Muṣṭafā Kāmil now turned to Sultan Abdülhamid. When a dispute (the Tābah Incident, 1906) arose between the Ottomans and the occupying power over the Sinai Peninsula, Muṣṭafā Kāmil sought to rally Egyptian nationalist opinion in favour of the Sultan, but Muṣṭafā Kāmil died in 1908.

British domination in Egypt and Cromer's personal ascendancy never seemed more secure than in the period following the Entente Cordiale. But the "veiled protectorate" had hidden weaknesses. Cromer was both out of touch and out of sympathy with the new generation of Egyptians. The occupation had become to all intents and purposes permanent, and the consequent growth of the British official establishment created frustration among educated Egyptians. The British, however, saw themselves as the benefactors of the Egyptian peasantry, whom they had delivered from the corvée and the lash. The Dinshawāy Incident showed them in another light. In June 1906 a fracas between villagers at Dinshawāy and a party of British officers out pigeon shooting resulted in the death of a British officer. The special tribunal set up to try the matter imposed exemplary and brutal sentences on the villagers. In the bitter aftermath of this affair, Cromer retired in May 1907.

The Dinshawāy Incident

Sir Eldon Gorst, who succeeded Cromer, had served in Egypt from 1886 to 1904 and brought a fresh mind to bear on the problems of the occupation. He obtained an understanding with the Khedive and endeavoured to diminish the growing power and numbers of the British establishment. At the same time he tried to give more effective authority to Egyptian political institutions. Muṣṭafā Fahmī's long premiership ended and he was followed by a Copt, Buṭrus Ghālī Pasha. When Gorst died prematurely in July 1911, he had attained only limited success. Many British officials resented his policies, which at the same time failed to conciliate the nationalists. A project for the extension of the Suez Canal Company's 99-year concession by 40 years was thrown out by the General Assembly (a quasi-parliamentary body, set up in 1883), while Buṭrus Ghālī, who had advocated it, was assassinated a few days later by a Muslim extremist. The appointment of Lord Kitchener to succeed Gorst portended the end of conciliation of the Khedive. But Kitchener, although autocratic, was not wholly conservative; his attempts to limit the power and influence of 'Abbās Ḥilmī served the interests of the nationalists. The Organic Law of 1913 created a new and more powerful Legislative Assembly that served as a training ground for the nationalist leaders of the post-war period. At the same time, the peasants were helped by improved agriculture and by legal protection of their holdings from seizure for debt.

World War I and independence. In November 1914 Britain declared war on the Ottoman Empire and in December proclaimed a protectorate over Egypt, deposed 'Abbās, and appointed his uncle, Ḥusayn Kāmil, with the title of sultan. Kitchener was succeeded by Sir Henry MacMahon, and he by Sir Reginald Wingate, both with the title of high commissioner. Although Egypt was not required to provide troops, the people, and particularly the peasantry, suffered from the effects of war. The declaration of martial law and the suspension of the Legislative Assembly curbed the activities of middle-class nationalists. Ḥusayn Kāmil died in October 1917 and was succeeded by his ambitious brother, Aḥmad Fu'ād.

On Nov. 13, 1918, two days after the Armistice, Wingate was visited by three Egyptian politicians headed by Sa'd Zaghlūl Pasha. Zaghlūl demanded autonomy for Egypt and announced his intention of leading a delegation (Arabic *wafd*) to state his case in England. The British government's refusal to accept a delegation, followed by the arrest of Zaghlūl, produced a widespread revolt in Egypt; and Lord Allenby, the victor over the Turks in Palestine, was sent out as special high commissioner. Allenby insisted on concessions to the nationalists in the hopes of reaching a settlement. Zaghlūl was released, and the Wafd, now a countrywide organization, dominated Egyptian politics. The Milner Commission (1919–20), sent to report on the establishment of constitutional government under the protectorate, was boycotted, but Milner subsequently had private talks with Zaghlūl in London. Finally, hoping to outmaneuver Zaghlūl and to build up a group of pro-British politicians in Egypt, Allenby pressed his government to promise independence without previously securing British interests by a treaty. The declaration of independence (Feb. 28, 1922) ended the protectorate but, pending negotiations, reserved four matters to the discretion of the British government: the security of imperial communications, defense, the protection of foreign interests and of minorities, and the Sudan. On March 15 the Sultan became King Fu'ād I of Egypt.

Attempt of Zaghlūl to secure Egypt's independence

The Kingdom of Egypt (1922–52). The new kingdom was in form a constitutional monarchy. The constitution, based on that of Belgium and promulgated in April 1923, defined the King's executive powers and established a bicameral legislature. An electoral law provided for universal male suffrage and the indirect election of deputies to the lower house: the Senate was half elected and half appointed. But Egyptian constitutionalism was as illusory as Egyptian independence. A political struggle was continually waged among three opportunist contestants—the King, the Wafd, and the British.

The interwar period. Fu'ād was never popular and felt insecure, and was therefore prepared to intrigue with the nationalists or with the British to secure his position and powers. The Wafd, with its mass following, elaborate organization, and (until his death in 1927) charismatic leader in Zaghlūl, was the only truly national party in Egypt. Ideologically, it stood for national independence against British domination and for constitutional government against royal autocracy. In practice—and increasingly as time went on—its leaders were prepared to make deals with the British or the King to obtain or retain power. Personal and political rivalries led to the formation of splinter parties, the first of which, the Liberal Constitutionalist Party, broke off as early as 1922. The primary aim of the British government, represented by its high

commissioner (after 1936, its ambassador), was to secure imperial interests, especially the control of communications through the Suez Canal. The need for a treaty to safeguard these interests led Britain on more than one occasion to conciliate nationalist feeling by supporting the Wafd against the King.

Political crises of the 1920s

The first general election, in January 1924, gave the Wafd a majority, and Zaghlūl became prime minister for a few months marked by unsuccessful treaty discussions with the British and tension with the King. When in November 1924 Sir Lee Stack, the sirdar and governor-general of the Sudan, was assassinated in Cairo, Allenby immediately presented an ultimatum that, though later modified by the British government, caused Zaghlūl to resign. The general election of March 1925 left the Wafd still the strongest party, but the Parliament no sooner met than it was dissolved. For more than a year Egypt was governed by decree. The third general election, in May 1926, again gave the Wafd a majority. The British frowned on a return of Zaghlūl to the premiership, and the office went instead to the Liberal Constitutionalist ʿAdlī Yegen (Yakan), while Zaghlūl held the presidency of the Chamber of Deputies until his death in 1927. Once again tension developed between the Parliament and the King, and in April 1927 ʿAdlī resigned, to be succeeded by another Liberal Constitutionalist, ʿAbd al-Khāliq Tharwat (Sarwat) Pasha, who negotiated a draft treaty with the British foreign secretary. The draft treaty, however, failed to win the approval of the Wafd. Tharwat resigned (March 1928), and Muṣṭafā an-Naḥḥās (Nahas) Pasha, Zaghlūl's successor, became prime minister. But the King dismissed him in June and dissolved the Parliament in July. In effect, the constitution was suspended, and Egypt was again governed by decree under a Liberal Constitutionalist premier, Muḥammad Maḥmūd Pasha.

Draft treaty proposals were agreed upon in June 1929, but since Maḥmūd was unable to overcome Wafdist opposition, British influence was thrown behind a return to constitutional government, hoping that a freely elected Parliament would approve the proposals. In the fourth general election (December 1929), the Wafd won a majority, and an-Naḥḥās again became prime minister. Resumed treaty negotiations broke down over the problem of the Sudan, from which the Egyptians had been virtually excluded since 1924. An-Naḥḥās also clashed with the King, whose influence he sought to curtail. He resigned in June 1930, and Fuʾād appointed Ismāʿīl Ṣidqī (Sidki) Pasha to the premiership. The constitution of 1923 was abrogated, and another was promulgated by royal decree. This, with its accompanying electoral law, strengthened the King's power. By this and other measures, Ṣidqī sought to break the power of the Wafd, which boycotted the general election of June 1931. The strong government of Ṣidqī lasted until September 1933, when he was dismissed by the King. Thereafter, for more than a year, palace-appointed governments ruled Egypt.

But Fuʾād, whose health was failing, could not hold out indefinitely against the internal pressure of the Wafd and the external pressure of Britain, which was becoming increasingly anxious for a treaty with Egypt. In April 1935 the constitution of 1923 was restored, and a general election in May 1936 gave the Wafd a majority once more. Fuʾād had died in the previous month and was succeeded by his son Farouk (Fārūq), still a minor. An-Naḥḥās became prime minister for the third time. Agreement was quickly reached with Britain, and a treaty of mutual defense and alliance was signed in August 1936. At the conference of Montreux, held in the following year, Egypt, with the backing of Britain, obtained the immediate abolition of the Capitulations and the extinction of the Mixed Courts after 12 years. In 1937 also, Egypt became a member of the League of Nations.

Treaty with Britain

An-Naḥḥās had reached the height of his power, but he was soon to be overthrown. In July 1937 the young king Farouk came of age and assumed his full royal powers. He was both popular and ambitious to rule, and tension rapidly developed between him and his prime minister. A split developed in the Wafd: Maḥmūd Fahmī an-Nuqrāshī (Nokrashy) Pasha and Aḥmad Māhir (Maher) Pasha were expelled and formed the Saʿdist Group. The Wafdist youth movement, known as the Blueshirts, was opposed by the Greenshirts of Young Egypt, a fascist organization. In December 1937 King Farouk dismissed an-Naḥḥās. In the ensuing general election (April 1938), the Wafd won only 12 seats.

World War II and its aftermath. Although at the outbreak of World War II in September 1939 Egypt provided facilities for the British war effort, few Egyptians were enthusiastic supporters of Britain and many expected its defeat. In 1940 the British brought pressure on the King to dismiss his prime minister, ʿAlī Māhir, and to appoint a more cooperative government. When, early in 1942, German forces prepared to invade Egypt, a second British intervention compelled King Farouk to accept an-Naḥḥās as prime minister. The Wafd, its power confirmed by overwhelming success in the general election of 1942, cooperated with Britain. Nevertheless, the intervention of February 1942 had disastrous consequences. It confirmed Farouk's hostility to both the British and an-Naḥḥās and tarnished the Wafd's pretensions as the standard-bearer of Egyptian nationalism. The Wafd was damaged also by internal rivalries.

An-Naḥḥās was dismissed by the King in October 1944. His successor, Aḥmad Māhir, was acceptable to the British, but he was assassinated in February 1945, at the moment of Egypt's declaration of war on Germany and Japan. He was succeeded by a Saʿdist, an-Nuqrāshī Pasha.

At the end of World War II, Egypt was in a thoroughly unstable condition. The Wafd declined and its political opponents took up the nationalist demand for a revision of the treaty of 1936—in particular for the complete evacuation of British troops from Egypt and the ending of British control in the Sudan. Politics was passing into the hands of radicals. The Muslim Brotherhood, founded in 1928, developed from an orthodox Islāmic reformist movement into a militant mass organization. Demonstrations in Cairo became increasingly frequent and violent. The pressure rendered it impossible for any Egyptian government to attempt a settlement of its two main external problems: the need to revise the treaty with Britain, and the wish to support the Arab cause in Palestine. Negotiations with Britain, undertaken by an-Nuqrāshī and (after February 1946) by his successor, Ṣidqī, broke down over the British refusal to prejudice the possible independence of the Sudan. Although Egypt referred the dispute to the United Nations in July 1947, the deadlock continued.

Anti-British demonstrations

Until the interwar period neither the Egyptian public nor the politicians had shown much interest in Arab affairs generally; Egyptian nationalism had developed as an indigenous response to local conditions. After 1936, however, Egypt became involved in the Palestine problem, and in 1943–44 it played a leading part in the formation of the Arab League. After World War II, Egypt became increasingly committed to the Arab cause in Palestine, but its unexpected and crushing defeat in the first Arab–Israeli War (1948–49), which had been launched with Syria, Iraq, and Jordan in response to the declaration of the State of Israel in May 1948, contributed to disillusionment and political instability. The Muslim Brotherhood increased its terrorist activities. An-Nuqrāshī, again prime minister, endeavoured to suppress the organization and was assassinated in December 1948. The Brotherhood's leader was murdered two months later.

A general election in January 1950 gave the Wafd a majority, and an-Naḥḥās again formed a government. Failing to reach agreement with Britain, in October 1951 he abrogated both the 1936 treaty and the Condominium Agreement of 1899. Anti-British demonstrations were followed by guerrilla warfare against the British garrison in the Canal Zone. British military action in Ismailia was followed on Jan. 26, 1952, by the burning of Cairo by demonstrators. An-Naḥḥās was dismissed, and there were four prime ministers in the ensuing six months.

(P.M.Ho./Ed.)

THE REVOLUTION AND THE REPUBLIC

The Nasser regime. At mid-century Egypt was ripe for revolution. Political groupings of both right and left pressed

The Free Officers

for radical alternatives. From an array of contenders for power, it was a movement of military conspirators—the Free Officers led by Col. Gamal Abdel Nasser—that toppled the monarchy in a coup in July 1952. In broad outline, the history of contemporary Egypt is the story of this coup, which preempted a revolution but then itself became a revolution from above. For three decades rule by Free Officers brought just enough advance at home and enhancement of standing abroad to make Egypt an island of stability in a turbulent Middle East.

The coup of July 1952 was fueled by a powerful but vague Egyptian nationalism rather than by a coherent ideology. It yielded a regime whose initially reformist character was given more precise form by a domestic power struggle and by the necessity of coming to terms with the British, who still occupied their base at Suez.

The domestic challenge to Nasser came in February–April 1954 from Gen. Mohammad Naguib, an older officer who served as figurehead for the Free Officers. Political parties had been abolished in January 1953. To supplement his power base in the military forces, Nasser drew on the police and on working-class support mobilized by the newly created mass political organization called the National Union. The small middle class, the former political parties, and the Muslim Brotherhood all rallied to Naguib. Nasser's triumph meant that a strong reliance on the military and security apparatus, coupled with carefully controlled manipulation of the civilian population, would be basic to the new system of rule.

Nasser's initial moderation

Obscured in the West was Nasser's initial moderation regarding Egypt's key foreign policy challenges—the Sudan, the British presence, and Israel. An agreement signed in 1954 established a transitional period of self-government for the Sudan, which became an independent republic in January 1956. Prolonged negotiations yielded the Anglo-Egyptian Treaty of 1954, under which British troops were to be evacuated gradually from the Canal Zone. Some Egyptians were critical, finding the treaty unsatisfactory from an Egyptian nationalist perspective. An attempt to assassinate Nasser by a member of the Muslim Brotherhood in October 1954 was used as a pretext to crush that organization.

In retrospect, it is clear that Nasser was the reluctant champion of the Arab struggle against Israel. Domestic development was his priority. A dangerous pattern of violent interactions, however, was evolving that would eventually draw the Egyptians into conflict with Israel. Small groups of Palestinian raiders, including some operating from Egyptian-controlled Gaza, were infiltrating Israel's borders. In October 1953 the Israeli government initiated the policy of large-scale retaliation that it pursued thereafter. One such strike—an attack on Gaza in February 1955 that left 38 Egyptians dead—exposed the military weakness of the Free Officer regime.

In September 1955 Nasser announced that an arms agreement had been signed between Egypt and Czechoslovakia (acting for the Soviet Union). The way to improved Soviet–Egyptian relations had been prepared by Nasser's refusal to join the Baghdad Pact (the Middle East Treaty Organization, later known as the Central Treaty Organization), which had been formed earlier that year by Turkey, Iraq, Iran, Pakistan, and the United Kingdom, with the support of the United States, to counter the threat of Soviet expansion. With the arms agreement of 1955, the Soviet Union eluded efforts to contain its actions and established itself as a force in the Middle East.

The erosion of Nasser's initially pro-Western orientation was accelerated further by the denial of funds previously promised by the United States and Britain for the construction of a high dam at Aswān. Defiantly, Nasser announced the nationalization of the Suez Canal Company in 1956 to finance the dam. In its subsequent attack on Egypt in October 1956, Israel was joined by the British, who were enraged by the nationalization, and the French, who were angered by Egyptian aid to the revolt in Algeria. Pressure on the invading powers by the United States and the Soviet Union, however, soon ended the so-called Suez War, leaving Nasser triumphant (despite his military losses) and with the Suez Canal firmly in Egyptian hands.

The Suez War of 1956

Nasser, who had been elected president in June 1956, pursued a more radical line in the decade following the Suez War. He launched an ambitious program of domestic transformation, a revolution from above that was paralleled by a drive for Egyptian leadership in the Arab world. Early in 1958 Egypt combined with Syria to form the United Arab Republic (U.A.R.), but it was a reluctant marriage of convenience and was dissolved in bitterness in September 1961 (Egypt retained the name United Arab Republic until 1971). The secession of Syria was blamed by Nasser on Syrian "reactionaries," and in direct response he pushed the revolution in Egypt further to the left. The following spring a National Charter proclaimed that Egypt's would be a regime of "scientific socialism" with a new mass organization, the Arab Socialist Union (ASU), to function in place of the National Union.

Impressive domestic gains were registered. In 1950 industry contributed 10 percent to the total national output; by 1970 that figure had increased to 21 percent. Unfortunately, these achievements in industry were not matched in agriculture, and they were further undercut by rapid population growth.

Throughout this period the potential military danger from Israel was a constant factor in the calculations of the U.A.R. government. It was a motive in strengthening ties with the Soviet bloc and producing a series of initiatives for cooperation among the Arab states, which, however, were disappointing. Nasser masked essential Egyptian moderation on the Israeli issue with a militant rhetoric of confrontation that was necessary to preserve his standing in the Arab world.

The failure of the union with Syria had been a blow to Nasser's pan-Arab standing. To regain the initiative, Nasser intervened in 1962–67 on the republican side of the Yemeni civil war. That intervention provoked conflict with Saudi Arabia, which supported the Yemeni royalists, and with the United States, which in turn supported the Saudis. Until then, Nasser had managed to obtain impressive aid from both the Soviet Union and the United States. Because of Egyptian intervention in the Yemen, U.S. aid was cut off in the mid-1960s.

Egyptian intervention in Yemen

This series of reversals was one key factor in the mood of desperation that pushed Nasser to abandon his policy of "militant inaction" toward Israel. For 10 years relative peace on the border with Israel was precariously maintained by the presence of a UN Emergency Force (UNEF) stationed on the Egyptian side. In the Arab summit conferences of the early 1960s Nasser had counseled restraint, but in 1966 events eluded his control. Palestinian incursions against Israel were launched with greater frequency and intensity from bases in Jordan, Lebanon, and, especially, Syria. A radical Syrian regime openly pledged support to the Palestinian guerrilla raids. On Nov. 13, 1966, an Israeli strike into Jordan left 18 dead and 54 wounded. Taunted openly for hiding behind the UNEF, Nasser was forced to act. The Egyptian president requested the withdrawal of the UNEF from the Sinai border. But that would include, as the United Nations interpreted the order, the removal of UN troops stationed at Sharm ash-Shaykh at the head of the Gulf of Aqaba. The posting of Egyptian troops there would mean the closing of the gulf to the Israelis.

Israel had made it clear that the closing of the gulf would be a cause for war. On June 5, 1967, Israel launched a preemptive attack on Egypt and Jordan later known as the June (or Six-Day) War. All of Egypt's airfields were struck, and the bulk of Egyptian planes were demolished on the ground. In the Sinai, Egyptian forces were defeated and put to flight. An estimated 10,000 Egyptians died. The Israelis reached the Suez Canal on June 9. Egypt was crushed and Nasser resigned. A popular outpouring of support, only partially manipulated by the government, refused the President's resignation. But the Nasser era was, in fact, over. In both domestic and foreign affairs, Nasser began a turn to the right that his successor, Anwar el-Sādāt, was to accelerate sharply.

Six-Day War of 1967

The Sādāt regime. Nasser died on Sept. 28, 1970, and was succeeded by his vice president, Sādāt, himself a Free Officer. Although regarded at the time as an interim figure,

Sādāt soon revealed unexpected gifts for political survival. In May 1971 he outmaneuvered a formidable combination of rivals for power, calling his victory the "Corrective Revolution." Sādāt then used his strengthened position to manage a war with Israel in October 1973, thereby setting the stage for a new era in Egypt's history.

October War of 1973

The Sādāt era really began with the October (or Yom Kippur) War of 1973. The sudden, concerted Syrian-Egyptian attack on October 6 surprised not only Israel but also the rest of the world. Egypt held no illusions that Israel could be vanquished. Rather, the war was launched with the diplomatic aim of convincing a chastened, if still undefeated, Israel to negotiate on terms more favourable to the Arabs. Preparation for the war included Sādāt's announcement in July 1972 that nearly all Soviet military advisers were to leave Egypt, partly because the U.S.S.R. had refused to sell offensive weapons to the Arab countries.

Egypt did not win the October War in any military sense. As soon as Israel recovered from the initial shock of Arab gains in the first few days of fighting—and once the United States abandoned its early neutrality and resupplied Israel with a massive airlift—the Israelis drove the Syrians and Egyptians back. A cease-fire was secured by the United States while Egyptian troops remained east of the Suez Canal and Israeli forces had crossed over to its western side.

Still, the initial successes in October 1973 enabled Sādāt to pronounce the war an Egyptian victory and to seek an honourable peace. Egyptian interests, as Sādāt saw them, dictated peace with Israel. Despite friction with his Syrian allies, Sādāt signed the Sinai I (1974) and Sinai II (1975) disengagement agreements that returned western Sinai and secured large foreign assistance commitments to Egypt. When Israeli inflexibility and Arab resistance combined and slowed events, Sādāt made a dramatic journey to Jerusalem in November 1977 to address Israel's legislature, the Knesset. Tortuous negotiations between Egypt and Israel ensued. The climactic meeting in September 1978 of Sādāt, Israeli Prime Minister Menachem Begin, and U.S. Pres. Jimmy Carter at Camp David, Md., led eventually to the Israeli–Egyptian treaty of March 26, 1979. The accord provided for peace between Egypt and Israel and set up a framework for resolving the Palestinian issue. Its provisions included the withdrawal of Israeli armed forces and civilians from Sinai within three years, special security arrangements in the peninsula, a buffer zone along the Sinai–Israel border to be manned by United Nations peacekeeping forces, the exchange of ambassadors, and the establishment of normal economic and cultural relations. The status of the Israeli-occupied West Bank and Gaza territories and the issue of Palestinian autonomy were to be negotiated.

Peace with Israel

Sādāt linked his peace initiative to economic reconstruction and proclaimed an open-door policy, hoping that a liberalized economy would be revitalized by the inflow of Western and Arab capital. The peace process did produce economic benefits, notably a vast U.S. aid program, begun in 1975, that exceeded $1 billion per year by 1981.

The Sādāt peace with Israel was not without its costs, however. As the narrowness of the Israeli interpretation of Palestinian autonomy under the Camp David agreement became clear, Sādāt could not convince the Arab world that the accords would ensure legitimate Palestinian rights. Egypt lost the financial support of the Arab states and, shortly after signing the peace treaty, was expelled from the Arab League.

At home, democratization of political life did not prove to be an acceptable substitute for economic revitalization. On Jan. 18–19, 1977, demonstrations provoked by economic hardship broke out in Egypt's major cities. An estimated 79 persons were killed, hundreds were wounded, and many hundreds more were jailed. The removal of the most oppressive features of Nasser's rule, the return in controlled form to a multiparty system, and (at least initially) the Sādāt peace with Israel were all welcomed. But, as Egypt entered the 1980s, the failure to resolve the Palestinian issue and to relieve economic hardships, heightened by the widening class gaps, undermined Sādāt's legitimacy. The West failed to notice this until, in September 1981, he arrested more than 1,300 of Egypt's political elite.

Egypt after Sādāt. Sādāt's assassination on Oct. 6, 1981, by members of the radical fringe of the Muslim religious opposition, was greeted in Egypt by a deafening calm. It was with a profound sense of relief that Egyptians brought Hosnī Mubārak, Sādāt's handpicked vice president, to power with a mandate for cautious change. As an air force general and hero of the October War, Mubārak had worked closely with Sādāt since 1973. (R.W.Ba.)

During his first year as president, Mubārak struck a moderate note, neither backing away from the peace with Israel nor loosening ties with the United States. By pursuing that steady course, he was able to prevent any delay in the return of the occupied Sinai to Egyptian sovereignty in April 1982. At the same time, Mubārak tried to contain the disaffections that had surfaced in the last year of Sādāt's era. He announced the end of the reign of the privileged minority that had dominated the invigorated private sector during the Sādāt years. He also released Sādāt's political prisoners while prosecuting vigorously the Islāmic militants who had plotted his assassination. Unfortunately, Egypt's economic problems could not be solved quickly. But in his very first speeches Mubārak did frankly and perceptively identify Egypt's economic shortcomings.

These solid beginnings were undercut when Israel invaded Lebanon in June 1982. In Egypt the invasion was perceived as an Israeli attempt to destroy Palestinian nationalism, and Mubārak was accused by his foes of letting Israel exploit Egypt's disengagement. Official relations with Israel were severely strained until that country's partial withdrawal from Lebanon in 1985. Mubārak's cautious policies did, on the other hand, enable Egypt to repair its relationships with most of the moderate Arab states. At an Arab summit in 1987, the heads of the Arab League authorized each member state to restore, individually, diplomatic relations with Egypt (Egypt was formally readmitted to the Arab League in 1989), and Iraq, which had been a leading critic of Sādāt's peace with Israel, purchased weapons and spare parts from Egypt during its war with Iran. (R.W.Ba./D.H./Ed.)

Like many of its Arab neighbours, however, Egypt sent troops to serve in the U.S.-led coalition against Iraq in the Persian Gulf War of 1990–91. Although Egypt was rewarded for its participation by forgiveness of billions of dollars that it owed for the purchase of arms from the West, many Egyptian workers were displaced because of Iraq's invasion of Kuwait, which added to Egypt's growing financial worries.

Social crises and the rise of Islāmism. Despite the government's efforts to achieve domestic stability, Egypt's economy continued to suffer in the late 1980s and early '90s, from both falling oil prices and a drop in the number of remittances from its three million workers abroad. In spite of a rising debt burden, the government continued to rely heavily on foreign economic aid, which led to growing interference by the International Monetary Fund in Egypt's economic policies. The Egyptian pound had to be devalued several times; interest rates were raised; and subsidies were lowered on food and fuel, which led to price increases and frequent food shortages. These policies especially afflicted the poorest Egyptians, who looked to Islāmist groups for emotional and financial succor. Thus strengthened, some extremists resorted to terrorism against political leaders—assassinating several government ministers and nearly killing Mubārak himself in Addis Ababa, Eth., in 1995—secularist writers, Copts, and even foreign tourists, a major source of Egypt's foreign exchange. In response, Mubārak's regime resorted to preventive detention and, allegedly, torture.

The end of the 20th century. Egypt continued to follow authoritarian patterns. Mubārak had been reelected to the presidency without opposition in 1987 and in 1993, and his National Democratic Party continued to increase its majority of the delegates in the People's Assembly in the elections held every five years. The Muslim Brotherhood, unofficially allowed to revive under Sādāt but never authorized to become a political party, threw its popular support behind various parties, but it was widely believed that voting results were rigged to ensure that Mubārak's supporters would win. Although Egypt's press was freer than

it had been under Nasser or Sādāt, Mubārak introduced a law in 1995 that allowed the imprisonment of journalists or party leaders who published material injurious to a government official. Popular pressure caused the Assembly to scale down this law, which was eventually voided by Egypt's Constitutional Court, but censorship persisted.

Many of Egypt's ongoing social and political problems resulted from the country's involvement on the side of the U.S.-led coalition against Iraq. Egypt's hopes that its contractors would get bids to rebuild Kuwait after the war were disappointed, and a plan to station Egyptian and Syrian troops as peacekeepers was rejected by the Gulf states, which were themselves a source of much animosity. Financially strapped Egyptians often expressed hostility at wealthy Saudis, Kuwaitis, and other Gulf Arabs who spent their vacations at the gaming tables and nightclubs in Cairo's luxury hotels. The public also grew skeptical at ongoing efforts by U.S. presidents and Mubārak to promote peace between Israel and other Arab countries or the Palestinians. Mubārak, unchallenged, was reelected for a fourth term in 1999. (Ed.)

For later developments in the history of Egypt, see the BRITANNICA BOOK OF THE YEAR.

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(L.S.El.H./Ma.J./C.G.S./D.H./J.R.Ba./A.K.B./D.S.Ri.)

Ancient Egyptian Arts and Architecture

In the general tradition of the visual arts of the West, ancient Egypt represents a source of form and technique dating back to the early 3rd millennium BC. For the purposes of definition ancient Egyptian is essentially coterminous with dynastic Egyptian, the dynastic structure of Egyptian history, artificial though it may partly be, providing a convenient chronological framework. The distinctive periods are: Early Dynastic (1st–3rd dynasties, *c.* 2925–*c.* 2575 BC); Old Kingdom (4th–8th dynasties, *c.* 2575–*c.* 2130 BC); First Intermediate (9th–11th dynasties, *c.* 2130–1939 BC); Middle Kingdom (12th–14th dynasties, 1938–*c.* 1600? BC); Second Intermediate (15th–17th dynasties, *c.* 1630–1540 BC); New Kingdom (18th–20th dynasties, 1539–1075 BC); Third Intermediate (21st–25th dynasties, *c.* 1075–656 BC); and Late Dynastic (26th–31st dynasties, 664–332 BC).

Geographical factors were predominant in forming the particular character of Egyptian art. By providing Egypt with the most predictable agricultural system in the ancient world, the Nile afforded a stability of life in which arts and crafts readily flourished. Equally, the deserts and the sea, which protected Egypt on all sides, contributed to this stability by discouraging serious invasion for almost 2,000 years. The desert hills were also rich in minerals and fine stones, ready to be exploited by artists and craftsmen. Only good wood was lacking, and the need for it led the Egyptians to undertake foreign expeditions to Lebanon, to Somalia, and, through intermediaries, to tropical Africa. In general, the search for useful and precious materials determined the direction of foreign policy and the establishment of trade routes and led ultimately to the enrichment of Egyptian material culture. For further treatment, see EGYPT; MIDDLE EASTERN RELIGIONS, ANCIENT.

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Predynastic Period

The term predynastic denotes the period of emerging cultures that preceded the establishment of the 1st dynasty in Egypt. In the late 5th millennium BC there began to emerge patterns of civilization that displayed characteristics deserving to be called Egyptian. The accepted sequence of predynastic cultures is based on the excavations of Sir Flinders Petrie at Naqādah, at al-'Āmirah (el-'Āmra), and at al-Jazīrah (el-Gezira). Another somewhat earlier stage of predynastic culture has been identified at al-Badārī in Upper Egypt.

From graves at al-Badārī, Dayr Tasa, and al-Mustaqiddah evidence of a relatively rich and developed artistic and industrial culture has been retrieved. Pottery of a fine red polished ware with blackened tops already shows distinctive Egyptian shapes. Copper was worked into small ornaments, and beads of steatite (soapstone) show traces of primitive glazing. Subsequently in the Naqādah I and Naqādah II stages predynastic civilization developed steadily. Pottery remains the distinctive product, showing refinement of technique and the development of adventurous decoration. Shapes already found in Badarian graves were produced in Naqādah I with superior skill and decorated with geometric designs of white-filled lines and even simple representations of animals. Later new clays were exploited, and fine buff-coloured wares were decorated in purple pigment with scenes of ships, figures, and a wide variety of symbols.

Refinement of pottery

The working of hard stones also began in earnest in the later Predynastic Period. At first craftsmen were devoted to the fashioning of fine vessels and to the making of jewelry incorporating semiprecious stones.

Sculpture found its best beginnings not so much in representations of the human form (although figurines, mostly female, were made from Badarian times) as in the carving of small animal figures and the making of schist (slate) palettes (intended originally for the preparation of eye paint). The Hunters and Battlefield palettes (British Museum; part of the former in the Louvre; part of the latter in the Ashmolean, Oxford) show two-dimensional representation—a convention that was to last 3,000 years.

The schist palettes

The basic techniques of two-dimensional art—drawing and painting—are exemplified in Upper Egyptian rock drawings and in the painted tomb at Hierakonpolis, now destroyed. Scenes of animals, boats, and hunting, the common subjects of rock drawings, were more finely executed in paint in the tomb, and additional themes, probably of conquest, presaged those found in dynastic art.

Dynastic Egypt

Evidence suggests that the unification of Upper and Lower Egypt drew together the various threads of what was to become the rich tapestry of Egyptian culture and started the intricate weave on the loom of time. Many of the new artistic developments undoubtedly can be traced back to the Naqādah II period; but the abundant evidence from the great tombs of the 1st dynasty at Abydos and Ṣaqqārah far outweighs what was found in the modest burials of earlier times. The impression is certainly one of an extraordinary efflorescence of civilization. Conquest, implicit in unification, is dramatically characterized in the scenes shown on the Narmer Palette (Egyptian Museum, Cairo), where Narmer, probably the founding king of dynastic Egypt, and better known as Menes, is depicted as the triumphant ruler (Figure 1).

The Narmer representations display much of what is typical of Egyptian art of the Dynastic Period. Here is the characteristic image of the king smiting his enemy, depicted with the conventions that distinguish Egyptian two-dimensional art. The head is shown in profile, but the eye in full; the shoulders are frontally represented, while the torso is at three-quarters view; the legs again are in profile. To show as much detail as possible was the principal intention of the artist—to show what he knew was

Conventions of two-dimensional representation

there, not simply what he could see from one viewpoint. Further conventions, well established by the 4th dynasty, included the showing of both hands and feet, right and left, without distinction. Scenes were set on baselines, and the events were placed in sequence, usually from right to left. Unity in a scene was provided by the focal figure of the most important person, the king or tomb owner. Relative size established importance: the ruler dwarfed the high official, while the tomb owner dwarfed his wife and, still more so, his children.

The canon of proportion

Conservatism in artistic matters was nurtured by a relative coherence of culture, strengthened by a vigorous tradition of scribal training, and tempered by a canon of proportion for the representation of the human figure. In the Old Kingdom, walls prepared for decoration were marked out with red horizontal guidelines; in later times vertical lines were added. During much of the Dynastic Period a grid of 18 rows of squares was used to contain the standing figure of a man; from the 26th dynasty, 21 rows of squares were used for the same purpose. At different periods, variations in the placing of specific bodily features produced interesting and subtle nuances. During the so-called Amarna period a distinctive reappraisal of the canon took place. The full range of changes and the many variants still remain to be studied, but it is clear that the basic canon lay deeply rooted in the training of the Egyptian artist.



Figure 1: Slate Narmer Palette, from Hierakonpolis, beginning of 1st dynasty, c. 2925 BC. In the Egyptian Museum, Cairo. Height 63.5 cm. (Left) Obverse, divided into three pictorial strips: the king, wearing the crown of Lower Egypt, shown on his way to witness the execution of fettered enemies; two bearded men leading two fabulous animals, perhaps symbolizing the unification of Upper and Lower Egypt; and the king in the form of a wild ox attacking a fortified settlement. (Right) Reverse, showing a victory motive: King Narmer, wearing the crown of Upper Egypt, striking down an enemy held by the hair.
Hirmer Fotoarchiv, München

ARCHITECTURE

The two principal building materials used in ancient Egypt were unbaked mud brick and stone. From the Old Kingdom onward stone was generally used for tombs—the eternal dwellings of the dead—and for temples—the eternal houses of the gods. Mud brick remained the domestic material, used even for royal palaces; it was also used for fortresses, the great walls of temple precincts and towns, and for subsidiary buildings in temple complexes.

Most ancient Egyptian towns have been lost because they were situated in the cultivated and flooded area of the Nile Valley; many temples and tombs have survived because they were built on ground unaffected by the Nile flood. Any survey of Egyptian architecture will in consequence be weighted in favour of funerary and religious buildings. Yet the dry, hot climate of Egypt has allowed some mud brick structures to survive where they have escaped the destructive effects of water or man.

Tomb architecture. Mortuary architecture in Egypt was highly developed and often grandiose. The tomb was not simply a place in which a corpse might be protected from desecration. It was the home of the deceased, provided with material objects to ensure continued existence after death. Part of the tomb might reproduce symbolically the earthly dwelling of the dead person; it might be decorated with scenes that would enable the individual to pursue magically an afterlife suitable and similar to his worldly existence. For a king the expectations were quite different; for him the tomb became the vehicle whereby he might achieve his exclusive destiny with the gods in a celestial afterlife.

The tomb as a home

Most tombs comprised two principal parts, the burial chamber (the tomb proper) and the chapel, in which offerings for the deceased could be made. In royal burials the chapel rapidly developed into a temple, which in later times was usually built separately and at some distance from the tomb. In the following discussion, funerary temples built separately will be discussed with temples in general and not as part of the funerary complex.

Royal tombs. In the earliest dynasties the tombs of kings and high officials were made of mud brick and of such similar size that it is difficult to distinguish between them. It is now generally thought that the tombs at Abydos were royal, whereas those at Ṣaqqārah were noble. The latter, better preserved than the former, reveal rectangular superstructures, called mastabas (see below), with sides constructed in the form of paneled niches painted white and decorated with elaborate "matting" designs.

These great superstructures contained many storage chambers stocked with food and equipment for the deceased, who lay in a rectangular burial chamber below ground. Also within the superstructure, but not always clearly evident, was a low mound of earth, possibly representing the primitive grave of earlier times. Sometimes this concealed mound was a low, stepped structure, perhaps the precursor of the first great building constructed of stone in Egypt.

The Step Pyramid of Djoser

The Step Pyramid of Djoser, second king of the 3rd dynasty, was built within a vast enclosure on a commanding site at Ṣaqqārah overlooking the city of Memphis. A high royal official, Imhotep, has traditionally been credited with the design and with the decision to use quarried stone. This first essay in stone is remarkable for its design of six superposed stages of diminishing size, and also for its huge enclosure (1,784 × 909 feet [544 × 277 metres]) surrounded by a paneled wall faced with fine limestone and containing a series of "mock" buildings that probably represent structures associated with the palace in Memphis. There the Egyptian stonemasons made their earliest architectural innovations, using stone to reproduce the forms of primitive wood and brick buildings. Fine reliefs of the king and elaborate wall "hangings" in glazed tiles in parts of the subterranean complexes are among the innovations found in this remarkable monument.

The Great Pyramid of Khufu

For the Old Kingdom the most characteristic form of tomb building was the true pyramid, the finest example of which is the Great Pyramid of King Khufu (Cheops) of the 4th dynasty at al-Jizah (Giza; Figure 2). The form itself reached its maturity in the reign of Snefru, father of Khufu. Subsequently only the pyramid of Khafre (Chephren), Khufu's successor, approached the size and perfection of the Great Pyramid. The simple measurements of the Great Pyramid indicate very adequately its scale, monumentality, and precision: its sides are 755.43 feet (230.26 metres; north), 756.08 feet (230.45 metres; south), 755.88 feet (230.39 metres; east), 755.77 feet (230.36 metres; west); its orientation on the cardinal points is almost exact; its height upon completion was 481.4 feet (146.7 metres); its area at base is just over 13 acres (5.3 hectares). Other features in its construction contribute substantially to its remarkable character: the lofty, corbeled Grand Gallery and the granite-built King's Chamber with five relieving compartments (empty rooms for reducing pressure) above.

The pyramid formed the focal point of a group of buildings that constituted the funerary complex of a king. Two temples linked by a causeway were essential components. The valley temple, built on the edge of the desert escarp-



Figure 2: The Pyramids of Giza with the Great Pyramid of King Khufu (Cheops), 4th dynasty (c. 2575–c. 2465 BC), to the right.
Ray Manley– Shostal Assoc.

ment, was the place of reception for the royal body. The most striking valley temple is that of Khafre, a structure of massive granite blocks with huge alabaster flooring slabs, starkly simple but immensely effective. The best preserved causeway serves the pyramid of King Unas of the 5th dynasty; it contains low-relief wall decorations and a ceiling adorned with stars. The pyramid temple of Unas is distinguished by the extensive use of granite for architectural elements, including doorways and splendid monolithic columns with palm capitals.

The pyramids built for the later kings of the Old Kingdom and most kings of the Middle Kingdom were comparatively poor in size, construction, and materials. The tomb of King Mentuhotep II of the 11th dynasty is, however, of exceptional interest. The tomb complex at Dayr al-Baḥrī was once thought to have contained a pyramid, but excavations between 1966 and 1971 have shown that the hypothetical reconstructions were misconceived. Its essential components were a rectangular structure, a series of pillared ambulatories, an open court, and a hypostyle hall tucked into the cliffs.

The monumentality of the pyramid made it not only a potent symbol of royal power but also an obvious target for tomb robbers. During the New Kingdom the wish to halt the robbing and desecration of royal tombs led to their being sited together in a remote valley at Thebes, dominated by a peak that itself resembled a pyramid.

The Valley of the Kings

There, in the Valley of the Kings, tombs were carved deep into the limestone with no outward structure and marked only by a doorway carved in the rock face. They had no common plan, but most consisted of a series of corridors opening out at intervals to form rooms and ending in a large burial chamber deep in the mountain. The finest of the tombs is that of Seti I, second king of the 19th dynasty; it extends 328 feet (100 metres) into the mountain and contains a spectacular burial chamber, the barrel-shaped roof of which represents the vault of heaven.

After the abandonment of the valley at the end of the 20th dynasty, kings of the subsequent two dynasties were buried in very simple tombs within the temple enclosure of the delta city of Tanis. No later royal tombs have ever been identified.

Private tombs. A major distinction between royal and nonroyal tombs lies in the provision of arrangements for the funerary cult of the deceased. The evidence available from the 3rd dynasty onward makes it clear that king and commoner had quite different expectations. In nonroyal tombs a chapel was provided that included a formal tablet or stela on which the deceased was shown seated at a table of offerings. The earliest examples are simple and architecturally undemanding; later a suitable room, the tomb-chapel, was provided for the stela (now incorporated in a false door) in the tomb superstructure, or mastaba.

The mastaba

The term mastaba (Arabic: "bench") was first used archaeologically in the 19th century by workmen on Auguste Mariette's excavation at Ṣaqqārah to describe the rectangular, flat-topped stone superstructures of tombs. Subsequently, mastaba was also used for mud brick superstructures.

In the great cemeteries of the Old Kingdom, changes in size, internal arrangements, and groupings of the burials of nobles indicate the vicissitudes of nonroyal posthumous expectations. In the 3rd dynasty at Ṣaqqārah the most important private burials were at some distance from the step pyramids of Djoser and Sekhemkhet. Their large superstructures incorporated offering niches that were to develop into chapels (as in the tomb of Khabausokar) and corridors that could accommodate paintings of equipment for the afterlife and niches to hold carved representations of the deceased owner (as in the tomb of Hesire). During the 4th dynasty the stone mastabas of the Giza pyramid field were regularly laid out near the pyramids, and, although smaller than those at Ṣaqqārah, they show the true start of the exploitation of space within the superstructure. The niche chapel became a room for the false door and offering table, and there might also be rooms containing scenes of offering and of daily activities.

Nothing indicates more clearly the relaxation of royal authority in the later Old Kingdom than the size and decoration of the mastabas at Ṣaqqārah and Abusīr. Externally they were still rectangular structures, occasionally with a low wall establishing a precinct (as in the tomb of Mereruka). The full exploitation of internal space in the great mastabas at Abusīr (that of Ptahshepses) and Ṣaqqārah (that of Ti and the double mastaba of Akhtihotep and Ptahhotep) made ample room available for the receipt of offerings and for the representation of the milieu in which the dead owner might expect to spend his afterlife. In the mastaba of Mereruka, a vizier of Teti, first king of the 6th dynasty, there were 21 rooms for his own funerary purposes, with six for his wife and five for his son.

Exploitation of internal space

Contemporaneously, the provincial colleagues of the

Memphite nobles developed quite different tombs in Middle and Upper Egypt. Tomb chapels were excavated into the rock of the cliffs overlooking the Nile. Rock-cut tombs subsequently were to become the most common kind of private tomb, although mastabas were built in the royal cemeteries of the 12th dynasty.

Rock-cut tombs

Most rock-cut tombs were fairly simple single chambers serving all the functions of the multiplicity of rooms in a mastaba. Some, however, were excavated with considerable architectural pretensions. At Aswān huge halls, often connecting to form labyrinthine complexes, were partly formal, with columns carefully cut from the rock, and partly rough-hewn. Chapels with false doors were carved out within the halls. In some cases the facades were monumental, with porticoes and inscriptions.

At Beni Hasan the local nobles during the Middle Kingdom cut large and precise tomb chambers in the limestone cliffs. Architectural features—columns, barrel roofs, and porticoes, all carved from the rock—provided fine settings for painted mural decorations. The tombs of Khnumhotep and Amenemhet are outstanding examples of fine design impeccably executed.

The most famous rock-cut private tombs are those of the New Kingdom at Thebes, their fame resting, above all, on their mural decoration. As elsewhere the excavated chambers are the tomb-chapels, mostly taking a simple T-form, in which the crossbar of the T represents the entrance hall, and the upright stroke of the T is the chapel proper. Some of the more important tombs (Rekhmire, Ramose) have open courts before their unelaborate facades and some striking internal features, but most are small in comparison with those of earlier times.

A separate tradition of private tomb design was developed for important officials at Ṣaqqārah in the New Kingdom. Open courts, constructed offering chapels, and elaborate subterranean suites of rooms characterize these Memphite tombs. The tomb for Horemheb, a military commander who became the last king of the 18th dynasty, has remarkable relief decoration. The tomb of Tia (a sister of the 19th-dynasty king Ramses II) has a small pyramid behind the chapel.

Temple architecture. Two principal kinds of temple can be distinguished—cult temples and funerary or mortuary temples. The former accommodated the images of deities, the recipients of the daily cult; the latter were the shrines for the funerary cults of dead kings.

Cult temples. It is generally thought that the Egyptian temple of the Dynastic Period owed most to the cult of the sun god Re at Heliopolis. The temple of Re, however, was probably open in plan and lacked a shrine. Sun temples were unique among cult temples; worship was centred on a cult object, the *benben,* which was a squat obelisk placed in full sunlight. Among the few temples surviving from the Old Kingdom are sun temples of the 5th-dynasty kings at Abū Jirāb (Abu Gurab). That of Neuserre reveals the essential layout: a reception pavilion at the desert edge connected by a covered corridor on a causeway to the open court of the temple high on the desert, within which stood the *benben* of limestone and a huge alabaster altar. Fine reliefs embellished the covered corridor and also corridors on two sides of the court.

Sun temples

The cult temple achieved its most highly developed form in the great sanctuaries erected over many centuries at Thebes. Architecturally the most satisfying, and certainly the most beautiful, is the Luxor Temple, started by Amenhotep III of the 18th dynasty. The original design consists of an imposing open court with colonnades of graceful lotus columns, a smaller offering hall, a shrine for the ceremonial boat of the god, an inner sanctuary for the cult image, and a room in which the divine birth of the king was celebrated. The approach to the temple was made by a colonnade of huge columns with open papyrus-flower capitals, planned by Amenhotep III but decorated with fascinating processional reliefs under Tutankhamen and Horemheb. Later Ramses II built a wide court before the colonnade and two great pylons to form a new entrance.

Temple at Luxor

The necessary elements of an Egyptian temple, most of which can be seen at Luxor, are the following: an approach avenue of sphinxes leading to the great double-towered pylon entrance fitted with flagpoles and pennants; before the pylon a pair of obelisks and colossal statues of the king; within the pylon a court leading to a pillared hall, the hypostyle, beyond which might come a further, smaller hall where offerings could be prepared; and at the heart of the temple, the shrine for the cult image. In addition, there were storage chambers for temple equipment and sometimes a crypt. Outside the main temple building was a lake, or at least a well, for the water needed in the rituals; in later times there might also be a birth house (*mammisi*) to celebrate the king's divine birth. The whole, with service buildings, was contained by a massive mud brick wall.

The great precinct of the Temple of Karnak (the longest side, 1,837 feet [560 metres]) contains whole buildings, or parts of buildings, dating from the early 18th dynasty down to the Roman Period. Modern reconstruction work has even recovered a tiny way station of the 12th dynasty, a gem of temple building decorated with some of the finest surviving relief scenes and texts.

The Karnak complex

Of the structures on the main Karnak axis the most remarkable are the hypostyle hall and the so-called Festival Hall of Thutmose III. The former contained 134 mighty papyrus columns, 12 of which formed the higher central aisle (76 feet [23 metres]). Grill windows allowed some light to enter, but it must be supposed that even on the brightest day most of the hall was in deep gloom.

The Festival Hall is better described as a memorial hall. Its principal room is distinguished by a series of unusual columns with bell-shaped capitals, inspired by the wooden tent poles used in primitive buildings. Their lightness contrasts strikingly with the massive supports of the hypostyle hall.

Near Karnak Temple, King Akhenaton and his wife, Nefertiti, built a number of temples, later dismantled, to the sun god Aton. The vast number of blocks found in modern times indicates that these constructions were essentially open places for worship like the earlier sun temples. So, too, was the great Aton temple at Tell el-Amarna, built later in Akhenaton's reign.

The most interesting and unusual cult temple of the New Kingdom was built at Abydos by Seti I of the 19th dynasty. Principally dedicated to Osiris, it contained seven chapels dedicated to different deities, including the deified Seti himself. These chapels have well-preserved barrel ceilings and are decorated with low-relief scenes retaining much original colour.

The most remarkable monument of Ramses II, the great builder, is undoubtedly the temple of Abu Simbel (Figure 3). Although excavated from the living rock, it follows generally the plan of the usual Egyptian temple: colossal seated statues emerging from the facade, which is the cliff face; a pillared hall followed by a second leading to a vestibule; and a shrine with four statues of divinities, including one of Ramses himself.

Temple of Abu Simbel

Mention should also be made of the immense temple dedicated to the god Amon-Re at Tanis in the delta by the kings of the 21st and 22nd dynasties. Much of the stone for the so-called northern Karnak, along with colossal statues and a dozen obelisks, was appropriated from other sanctuaries in Egypt, making this a remarkable assemblage of earlier work. It was not only a cult temple but the funerary temple for the kings who were buried within the precinct.

Funerary temples. Most of the New Kingdom funerary temples were built along the desert edge in western Thebes. An exception, and by far the most original and beautiful, was Queen Hatshepsut's temple, designed and built by her steward Senenmut near the tomb of Mentuhotep II at Dayr al-Baḥrī. Three terraces lead up to the recess in the cliffs where the shrine was cut into the rock. Each terrace is fronted by colonnades of square pillars protecting reliefs of unusual subjects, including an expedition to Punt and the divine birth of Hatshepsut. Ramps lead from terrace to terrace, and the uppermost level opens into a large court with colonnades. Chapels of Hathor (the principal deity of the temple) and Anubis occupy the south and north ends of the colonnade of the second terrace.

The largest conventionally planned funerary temple was

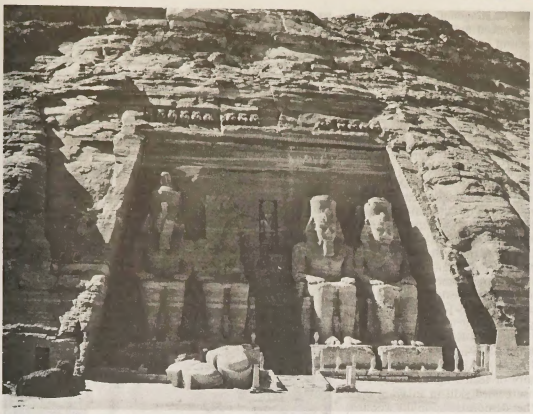

Figure 3: Entrance to the Nubian cliff temple of Ramses II at Abu Simbel, Egypt, *c.* 1250 BC, New Kingdom, 19th dynasty.
H. Roger-Viollet

probably that of Amenhotep III, now to be judged principally from the two huge quartzite statues, the Colossi of Memnon. These and other royal sculptures found in the ruins of the temple's courts and halls testify to the magnificence now lost. Its design, as well as much of its stone, was used by Ramses II for his own funerary temple, the Ramesseum. The huge enclosure of the latter included not only the temple but also a royal palace (only traces of which can now be seen). The temple itself contained two huge open courts, entered through towering pylons, which led to a lofty hypostyle hall and a smaller hall with astronomical carvings on the ceiling. Statues of vast size stood before the second pylon, one of which, now toppled and ruined, has been estimated as weighing more than 1,000 tons. Mud brick storerooms in the enclosure preserve ample evidence of the use of the vault in the late 2nd millennium BC.

Temple at Madīnat Habu

Ramses III's funerary temple at Madīnat Habu contains the best preserved of Theban mortuary chapels and shrines, as well as the main temple components. The most private parts of the temple, to which few had access apart from the king and his priestly representatives, begin at the sides of the first hypostyle hall, with the temple treasury and a room for the processional boat of Ramses II (a much-honoured ancestor) on the south and shrines for various deities, including Ramses III, on the north. A second pillared hall is flanked by a solar chapel and a small Osiris complex, where the king took on the personae of Re, the sun-god, and of Osiris, god of the underworld, a transfiguration considered necessary for his divine afterlife. Beyond the Osiris complex, along the temple axis, is a third small hall and the main shrine for the Theban god Amon; two lateral shrines were reserved for Amon's consort Mut and their divine child Khons.

As with most New Kingdom temples, the mural decorations on the outer walls of funerary temples, including that at Madīnat Habu, dealt mainly with the military campaigns of the king, while the inner scenes were mostly of ritual significance. Within the temple precinct lived and worked a whole community of priests and state officials. A small palace lay to the south of the main building, and a further suite of rooms for the king was installed in the castellated gate building on the east side of the precinct. The reliefs in this "high gate" suggest that the suite was used for recreational purposes by the king together with his women.

Domestic architecture. Mud brick and wood were the standard materials for houses and palaces throughout the Dynastic Period; stone was used occasionally for such architectural elements as doorjambs, lintels, column bases, and windows.

The best preserved private houses are those of modest size in the workmen's village of Dayr al-Madīnah. Exceptional in that they were built of stone, they typically had three or four rooms, comprising a master bedroom, a reception room, a cellar for storage, and a kitchen open to the sky; accommodation on the roof, reached by a stair, completed the plan.

The workman's house

Villas for important officials in Akhenaton's city of Tell el-Amarna were large and finely decorated with brightly painted murals. The house of the vizier Nakht had at least 30 rooms, including separate apartments for the master, his family, and his guests. Such houses had bathrooms and lavatories. The ceilings of large rooms were supported by painted wooden pillars, and there may have been further rooms above. Where space was restricted (as in Thebes) houses of several stories were built. Tomb scenes that show such houses also demonstrate that windows were placed high to reduce sunlight and that hooded vents on roofs were used to catch the breeze.

Palaces, as far as can be judged from remains at Thebes and Tell el-Amarna, were vast, rambling magnified versions of Nakht's villa, with broad halls, harem suites, kitchen areas, and wide courts. At Tell el-Amarna some monumental formality was introduced in the form of porticoes, colonnades, and statuary. Lavish use was made of mural and floor decoration in which floral themes predominated.

SCULPTURE

The Egyptian artist, whose skills are best exemplified in sculpture, regarded himself essentially as a craftsman. Owing to his discipline and highly developed aesthetic sense, however, the products of his craft deserve to rank as art outstanding by any standards.

Much of the surviving sculpture is funerary—statues for tombs. Most of the remainder was made for placing in temples—votive for private persons and ritual for royal and divine representations. Royal colossi were ritual and also served to proclaim the grandeur and power of the king. By itself, however, a statue could represent no one unless it carried an identification in hieroglyphs.

Emergence of types in the Old Kingdom. The standing male figure with left leg advanced and the seated figure were the most common types of Egyptian statuary. Traces of wooden figures found at Ṣaqqārah show that the first type was being made as early as the 1st dynasty. The earliest seated figures are two of King Khasekhem of the 2nd dynasty (Egyptian Museum, Cairo, and Ashmolean, Oxford), which, although relatively small, already embody the essential monumentality of all royal sculpture.

Supreme sculptural competence was achieved remarkably quickly. The primitive, yet immensely impressive life-size statue of Djoser (Egyptian Museum) pointed the way to the magnificent royal sculptures from the 4th-dynasty pyramid complexes at Giza. For subtlety of carving and true regal dignity scarcely anything of later date surpasses the diorite statue of Khafre (Egyptian Museum). Scarcely less fine are the sculptures of Menkaure (Mycerinus). The pair statue of the king and his wife (Museum of Fine Arts, Boston) exemplifies wonderfully both dignity and marital affection (Figure 4); the triads showing the king with goddesses and nome (provincial) deities exhibit a complete mastery of carving hard stone in many planes.

This union of skill and genius was achieved in nonroyal statuary more frequently in the Old Kingdom than later. The painted limestone statues of Prince Rahotep and his wife, Nofret (Egyptian Museum), exemplify this achievement in the formal category of seated figures. They also display the Egyptian's unsurpassed skill in inlaying eyes into sculptures, a skill further demonstrated in the wooden figure of Ka'aper, known as Shaykh al-Balad (Egyptian Museum), the very epitome of the self-important official (see Figure 8).

Scribal statues

Among additions to the sculptural repertoire during the Old Kingdom was the scribal statue. Examples in the Louvre and in the Egyptian Museum express brilliantly the alert vitality of the bureaucrat, squatting on the ground with brush poised over papyrus. The heads of such figures possess striking individuality, even if they are not true portraits.

Refinements of the Middle Kingdom. Changes in funerary practices during the Middle Kingdom led to a reduction in the number of sculptures. Royal sculptures, particularly of Sesostris III and Amenemhet III (British Museum), achieved a high degree of realism, even of portraiture. The first true royal colossi were produced in the 12th dynasty (if the Great Sphinx of Giza is discounted) for the embellishment of cult temples. Colossi of Amenemhet I and Sesostris I (Egyptian Museum) exhibit a hard, uncompromising style said to typify the ruthless drive of the 12th-dynasty kings.

In this period, too, the sphinx—the recumbent lion with head or face of the king—became a commonly used image of the king as protector. The great red granite sphinx of Amenemhet II from Tanis (Louvre) expresses the idea most potently.

In private sculpture during the Middle Kingdom the subject is in most cases portrayed seated or squatting, occasionally standing, and wearing an all-enveloping cloak. The body was mostly concealed, but its contours were often subtly suggested in the carving, as in the figure of Khertyhotep (Agyptisches Museum, Berlin). Of female subjects, none is more impressive than that of Sennu (Museum of Fine Arts, Boston), a wonderful example of a figure in repose.

Block statues

The simplification of the human figure was carried to its ultimate in the block statue, a uniquely Egyptian type that represents the subject squatting on the ground with knees drawn up close to his body. The arms and legs may be wholly contained within the cubic form, hands and feet alone discretely protruding. The 12th-dynasty block statue of Sihathor (British Museum) is the earliest dated example.

Innovation, decline, and revival in the New Kingdom. Excellence of craftsmanship is the hallmark of 18th-dynasty sculpture, in a revival of the best traditions of the Middle Kingdom. Wonderfully sensitive statues of Hatshepsut and Thutmose III confirm the return of conditions in which great work can be achieved. A seated limestone statue of Hatshepsut (Metropolitan Museum of Art, New York City) shows the queen as king, but with an expression of consummate grace. A schist statue of Thutmose III (Luxor Museum), in the perfection of its execution and subtlety of its realization, epitomizes regality.



Figure 4: King Menkaure and Queen Khamerernebty II, slate sculpture from Giza, Egypt, *c.* 2525 BC. Old Kingdom, 4th dynasty. In the Museum of Fine Arts, Boston. Height 1.42 m.
By courtesy of the Museum of Fine Arts, Boston. Museum Expedition

The placing of votive statues in temples led to a proliferation of private sculptures during the New Kingdom. The sculptures of Senenmut, steward of Hatshepsut, exemplify the development. At least 23 votive statues (some fragmentary) of this royal favourite are known, exhibiting many different forms.

Colossal sculpture

Colossal sculpture, which reached its apogee in the reign of Ramses II, was used to splendid, and perhaps less bombastic, effect by Amenhotep III. The great sculptures of his funerary temple, already mentioned, including the immense Colossi of Memnon, were part of the noble designs of his master of works, also called Amenhotep (son of Hapu). Most unusually, this distinguished commoner was allowed a funerary temple for himself and larger-than-life votive sculptures (Egyptian Museum and Luxor Museum) that show him in contrasting attitudes, as stern-faced authoritarian and as submissive scribe.

The realistic portraiture that can be noted in certain sculptures of Amenhotep III (British Museum) hints of an artistic change that was developed in the subsequent reign of Akhenaton. The distinctive style of this period has come to be called Amarna, after the location of Akhenaton's new capital in Middle Egypt. Colossal sculptures of the King from the dismantled Karnak temples (Egyptian Museum) emphasize his bodily peculiarities—elongated facial features, heavy breasts, and swelling hips (Figure 5). Sculptures of Nefertiti, his queen, are often executed in the most remarkably sensual manner (*e.g.*, the Louvre torso). Sculptures from later in the reign display innovations of style with no loss of artistry, at the same time avoiding the grotesqueries of the early years. Of this period is the famous painted bust of Nefertiti (Agyptisches Museum).

The reign of Ramses II

Much of the best of the artistic legacy of Akhenaton's reign persisted in the sculpture of subsequent reigns—Tutankhamen, Horemheb, and the early kings of the 19th dynasty—but a marked change came in the reign of Ramses II. It is a commonplace to decry the quality of his monumental statuary, although little in Egypt is more dra-



Figure 5: King Akhenaton, sandstone pillar statue from the Temple of Aton at Karnak, Egypt, New Kingdom, 18th dynasty (mid-14th century BC). In the Egyptian Museum, Cairo. Height 4.00 m.
Hirmer Fotoarchiv, München

matic and compelling than the great seated figures of this king at Abu Simbel. Nevertheless, there is much truth in the belief that the steady decline in sculpture began during Ramses II's reign. Royal portraiture subsequently became conventional. Occasionally a sculptor might produce some unusual piece, such as the extraordinary figure of Ramses VI with his lion, dragging beside him a Libyan prisoner (Egyptian Museum). Among private sculptures there is the scribal statue of Ramsesnakht (Egyptian Museum); the subject bends over his papyrus while Thoth (the divine scribe), in baboon form, squats behind his head.

A change was to come with the advent of the Kushite (Nubian) kings of the 25th dynasty. The portraiture of the Kushite kings exhibits a brutal realism that may owe much to the royal sculpture of the 12th dynasty; the sphinx of Taharqa, fourth king of the 25th dynasty (British Museum), is a good example.

Archaism is strikingly evident in the private sculpture of the last dynasties. Types of statue common in the Middle Kingdom and 18th dynasty were revived, and many very fine pieces were produced. The sculptures of the mayor of Thebes, Montemhat (Egyptian Museum), display great variety, excellent workmanship, and, in one case, a realism that transcends the dictates of convention.

In considering the clear sculptural qualities of Late Period work one should never overlook the primary purpose of most Egyptian sculpture: to represent the individual in death before Osiris, or in life and death before the deities of the great temples. To this end the statue was not only a physical representation but also a vehicle for appropriate texts, which might be inscribed obtrusively over beautifully carved surfaces. The extreme example of such "disfigurement" is a so-called healing statue (Louvre) of which even the wig is covered with texts.

RELIEF SCULPTURE AND PAINTING

For Egyptians the decoration of tomb walls with reliefs or painted scenes provided some certainty of the perpetuation of life; in a temple, similarly, it was believed that mural decoration magically ensured the performance of important ceremonies and reinforced the memory of royal deeds.

Importance of mural decoration

The beginnings of the dynastic tradition can be found in tombs of the 3rd dynasty, such as that of Hesire at Ṣaqqārah; it contained mural paintings of funerary equipment and wooden panels carrying figures of Hesire in the finest low relief (Egyptian Museum; see Figure 8). Generally speaking, mural decorations were in paint when the ground was mud brick or stone of poor quality, and in relief when the walls were in good stone. Painting and drawing formed the basis of what was to be carved in relief, and the finished carving was itself commonly painted.

In tombs the mural decorations might be left unfinished, being only partly sketched or partly carved by the time of the burial. Uncompleted scenes reveal clearly the methods of laying out walls for decoration. The prepared wall was marked out with red guidelines, the grid described earlier being used for major human figures and sometimes for minor ones. Preliminary outlines were corrected and paint was applied usually in tempera, pigments being mostly mineral-based.

In the Old Kingdom pure painting of the highest quality is found as early as the 4th dynasty in the scene of geese from the tomb of Nefermaat and Atet at Maydum. But the glory of Old Kingdom mural decoration is the low-relief work in the royal funerary monuments of the 5th dynasty and in the private tombs of the 5th and 6th dynasties in the Memphite necropolis. Outstanding are the reliefs from the sun temple of King Neuserre at Abu Jirab (Ägyptisches Museum, East and West Berlin) and the scenes of daily life in the tombs of Ptahhotep and Ti at Ṣaqqārah.

The tradition of fine painting was continued in the Middle Kingdom. At Beni Hasan the funerary chambers are crowded with paintings exhibiting fine draftsmanship and use of colour. The best relief work of the period, reviving the Memphite tradition, is found at Thebes in the tomb of Mentuhotep II at Dayr al-Baḥrī and in the little shrine of Sesostris I at Karnak, where the fine carving is greatly enhanced by a masterly use of space in the disposition of figures and text.

In the early 18th dynasty the relief tradition was revived at Thebes and can best be observed in the carvings in Hatshepsut's temple at Dayr al-Baḥrī. Later royal reliefs of Amenhotep III and of the post-Amarna kings show a stylistic refinement that was carried to its best in the reign of Seti I, at Karnak, at Abydos, and in his tomb at Thebes.

The 18th dynasty also saw Egyptian painting reach its highest achievement in the tombs of the nobles at Thebes (Figure 6). The medium of decoration and an apparently

High point of Egyptian painting

By courtesy of the Trustees of the British Museum



Figure 6: Banquet scene with musicians, tempera painting on gesso from the tomb of Nebamun at Thebes, 18th dynasty (c. 1400 BC). In the British Museum.

greater artistic freedom led to the introduction of small, often entertaining details into standard scenes. The tiny tombs of Menna and Nakht are full of such playful vignettes. The paintings in great tombs, such as that of Rekhmire, are more formal but still crammed with unusual detail. Fragments of mural and floor paintings from palaces and houses at Thebes and Tell el-Amarna provide tantalizing glimpses of the marsh and garden settings of everyday upper-class life.

The fine royal reliefs of the late 18th dynasty were matched by those in private tombs at Thebes (Ramose and Kheruef) and Saqqārah (Horemheb); these are breathtaking in execution and, in the case of Horemheb, both moving and original. Interest in relief subsequently passed to the work in the temples of the 19th and 20th dynasties. The most dramatic subject was war, whether the so-called triumph of Ramses II at Kadesh (Thebes and Abu Simbel), or the more genuine successes of Ramses III against the Libyans and the Sea Peoples (Madinat Habu). The size and vitality of these ostentatious scenes are stupendous, even if their execution tends to be slapdash.

The artistic renaissance of the 25th and 26th dynasties is less evident in painting and relief than in sculpture. Although the fine work in the tomb of Montemhat at Thebes is distinctly archaizing, it is, nevertheless, exceptional in quality. The skills of the Egyptian draftsman, nurtured by centuries of exercise at large and small scale, remained highly professional. This skill is seen at its most consistent level in the illumination of papyruses. The practice of including drawings, often painted, in religious papyruses flourished from the time of the 18th dynasty and reached a high point around 1300 BC. The peak of achievement is probably represented by the *Book of the Dead* of the scribe Ani (British Museum), in the vignettes of which both technique and the use of colour are outstanding. Subsequently, and especially in the Late Period, pure line drawing was increasingly employed.

Illumination of papyruses

PLASTIC ARTS

In Egypt pottery provided the basic material for vessels of all kinds. Fine wares and many other small objects were made from faience. Glass arrived late on the scene and was used somewhat irregularly from the New Kingdom onward.

Pottery. Generally speaking, Egyptian pottery had few artistic pretensions. In the tomb of Tutankhamen most of the pottery vessels were simple wine jars in the form of amphorae. It is surprising that no finer pottery vessels were found, because high-quality ware was made during the late 18th and 19th dynasties, often brightly painted with floral designs.

Pottery was rarely modeled, although human and animal figures occur in small numbers throughout the Dynastic Period. Small vessels in animal form were also made, especially during the Middle and New Kingdoms, and a fine category of highly burnished red pottery vases in female form was produced during the 18th dynasty.

Faience. The place of pottery for modeling was filled with faience (a glazed composition of ground quartz), most commonly blue or green in colour. In the Early Dynastic Period it was much used for the making of small animal and human figures, and throughout the Dynastic Period it continued to be used in this way, among the most striking results being the blue-glazed hippopotamus figures of Middle Kingdom date.

Hippopotamus figures

In the Late Period, in particular, the making of amulets and divine figurines in faience was highly developed, and many pieces display a high standard of modeling and perfection of glazing. The vast quantities of *ushabti* (*shabti*, or *shawabti*) figures provided as parts of funerary equipments are mostly routine work, but the finest examples from the New Kingdom, and some of Saite date, show complete mastery of a difficult technique.

Faience tiles were also first made in the early dynasties and were used chiefly for wall decoration, as in the subterranean chambers of the Step Pyramid. In the New Kingdom, tiles with floral designs were used in houses and palaces in the reigns of Amenhotep III and his successors. During the 19th and 20th dynasties royal palaces at Per Ramessu (modern Qantīr), Tell al-Yahudīyah, and Madīnat Habu were embellished with remarkable polychrome tiles, many of which bear figures of captive foreigners.

Throughout the Dynastic Period faience was regularly used for simple beads, amulets, and other components of jewelry. Quite exceptional is the extraordinary *was*-sceptre (a symbol of divine power) found at Tūkh, near Naqādah (Victoria and Albert Museum, London). It is dated to the reign of Amenhotep II and originally measured about six and a half feet (two metres) in length.

Glass. In the form of glaze, glass was known to the ancient Egyptians from early predynastic times, but the material was not used independently until the 18th dynasty. From the mid-18th dynasty and during the 19th dynasty glass was used for small amulets, beads, inlays, and especially for small vessels. The material was opaque, blue being the predominant colour, although other bright colours were also achieved. The vessels, made around sand cores, were mostly drinking cups or flasks for precious liquids and were often decorated with trailed patterns applied as glass threads. Glass was certainly a material of luxury, a fact confirmed by the presence of two glass goblets with gold rims among a treasure of precious vessels from the reign of Thutmose III (Metropolitan Museum of Art).

The use of glass for inlay is notably demonstrated in Tutankhamen's golden throne, in his solid gold mask, and in much of his jewelry (Figure 7). After the 19th dynasty, glass manufacture seems largely to have been discontinued until the Late Period,when the use of glass for inlays was revived.

Glass inlay

DECORATIVE ARTS

Jewelry. Gold provided Egyptian jewelry with its richness; it was used for settings, cloisonné work, chains, and beads, both solid and hollow. Soldering, granulation, and wire making were practiced. Precious stones were not used, but a wide range of semiprecious stones was exploited: carnelian, amethyst, garnet, red and yellow jasper, lapis lazuli, feldspar, turquoise, agate. Additional colours and textures were provided by faience and glass.

Ancient Egyptian jewelers had a fine eye for colour and an excellent sense of design. From the earliest dynasties come bracelets from the tomb of King Djer at Abydos (Egyptian Museum); from the 4th dynasty, the armlets of Queen Hetepheres, of silver inlaid with carnelian, turquoise, and lapis lazuli (Egyptian Museum and Museum of Fine Arts). There are examples of splendid and delicate jewelry dating from the Middle Kingdom: in particular, pieces found at Dahshūr and al-Lāhūn—circlets of Princess Khnumet

By courtesy of the Egyptian Museum, Cairo.
Photograph, Eliot Elisofon, Life, c. 1946, Time, Inc.

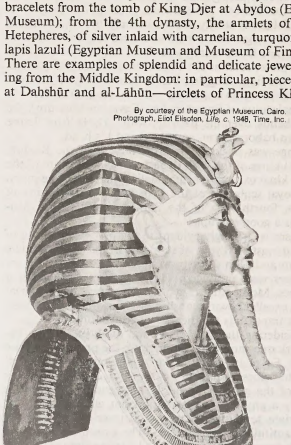

Figure 7: Gold funerary mask of the pharaoh Tutankhamen inlaid with lapis lazuli and coloured glass, New Kingdom, 18th dynasty (c. 1323 BC). In the Egyptian Museum, Cairo. Height 53.3 cm.

(Egyptian Museum), pectorals of Princess Sithathor and Queen Meret (Egyptian Museum), and girdles of Princess Sithathor-iunet (Metropolitan Museum of Art).

The large and spectacular collection of jewelry buried with Queen Ahhotep of the early 18th dynasty (Egyptian Museum) includes many unusual designs; her gold chain is a masterpiece. Much fine 18th-dynasty jewelry has survived, but all is dominated by that of Tutankhamen (Egyptian Museum). This huge collection demonstrates all the techniques of the goldsmith's and the lapidary's arts.

Copper and bronze. The techniques of metalworking were probably introduced into Egypt from the Middle East at a very early date. At first copper was most commonly used; but from at least the late 3rd millennium it was often alloyed with tin, as bronze.

The skill and artistry of the metalworker is shown in the fine bowls, jugs, and other vessels from all periods, and in statues and statuettes of gods, kings, and ordinary mortals. Most vessels were made by raising from metal ingots, beaten on wooden anvils. In the Late Period many vessels were produced by casting. Huge situlae, vessels used for carrying sacred liquids, are often decorated with scenes and inscriptions.

Casting of figures

The earliest and largest metal figure from Egypt is the life-size statue of Pepi I (Egyptian Museum) made of copper plates fitted to a wooden core, the plates probably beaten, not cast. Casting in open molds was developed early for tools and weapons, but the lost-wax process (*cire-perdue*), using closed molds, was not employed until the Middle Kingdom. Even in the 18th dynasty the casting of bronze figures occurred on a relatively small scale.

The casting of large-scale bronze figures achieved its highest point in the late New Kingdom down to the 25th dynasty. The outstanding example from this period is the figure of Karomama (Louvre). The exceptionally elegant modeling of the female form is greatly enriched by inlays of gold and silver reproducing the feathered pattern of the gown and an elaborate collar of floral motifs.

In the Late Period huge numbers of excellent castings of conventional sacred figures and animals were produced. The so-called Gayer-Anderson cat (British Museum) is technically and artistically without peer.

Decorative uses of gold

Gold and silver. Gold was more easily obtainable in ancient Egypt than silver and was therefore less valuable (until the late New Kingdom). Gold was also easier to work and unaffected by environmental conditions. In consequence, many more gold than silver objects have survived.

Apart from jewelry, gold was lavishly used for many decorative purposes, as thin sheet, leaf, and inlay, in funerary equipment, and for vessels and furniture. The range of uses is best exemplified in the objects from the tomb of Tutankhamen.

The gold-plated, gold-inlaid furniture of Queen Hetepheres of 4th-dynasty date reveals how early Egyptian craftsmen mastered the working of gold. Gold vessels have rarely survived, but those from the royal burials of Tanis (Egyptian Museum) preserve styles and techniques that go back to the traditions of the New Kingdom and earlier. Gold statuettes also are rare, but again, surviving examples, such as the magnificent falcon head of a cult statue of 6th-dynasty date from Hierakonpolis and the divine triad of Osiris, Isis, and Horus of the 22nd dynasty (Louvre), show the achievements of early and late times.

In a hoard of precious vessels found at Bubastis and dated to the 19th dynasty (Egyptian Museum) there were three silver pieces of exceptional interest, in particular a jug the handle of which is of gold and in the shape of a goat. Greater availability of silver in later times is demonstrated by two massive silver coffins and a number of vessels in the royal burials at Tanis (Egyptian Museum).

Cabinet-making

Wood. The wooden sculpture of the Old Kingdom shows the carver of wood at his most skillful and sensitive (Figure 8). But it is in the field of cabinetmaking that the ancient woodworker excelled. Best known are the many chairs, tables, stools, beds, and chests found in Tutankhamen's tomb. Many of the designs are exceptionally practical and elegant. Techniques of inlay, veneering, and marquetry are completely mastered. One chest is veneered with strips of ivory and inlaid with 33,000 small pieces of ivory and ebony. Fine furniture was being produced in very early times, as is confirmed by the skillfully restored furniture from the secondary burial of Hetepheres (Egyptian Museum and Museum of Fine Arts).

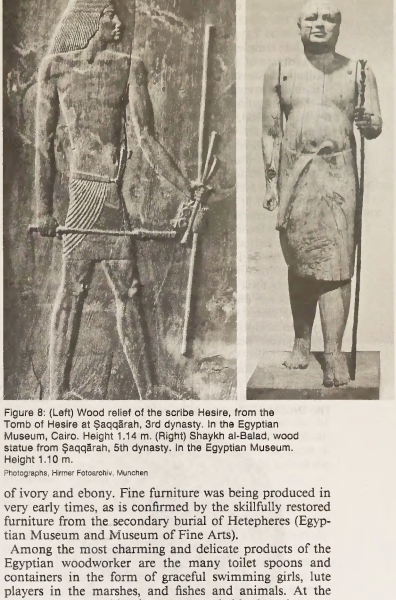

Figure 8: (Left) Wood relief of the scribe Hesire, from the Tomb of Hesire at Ṣaqqārah, 3rd dynasty. In the Egyptian Museum, Cairo. Height 1.14 m. (Right) Shaykh al-Balad, wood statue from Ṣaqqārah, 5th dynasty. In the Egyptian Museum. Height 1.10 m.
Photographs, Hirmer Fotoarchiv, München

Among the most charming and delicate products of the Egyptian woodworker are the many toilet spoons and containers in the form of graceful swimming girls, lute players in the marshes, and fishes and animals. At the other extreme, nothing is more remarkable than the great boat, more than 140 feet (43 metres) long, found in a trench by the side of the Great Pyramid.

Ivory figurines

Ivory and bone. Of the few small ivory figurines to have survived from pharaonic times, two royal representations found in the Early Dynastic temple at Abydos (Egyptian Museum and British Museum) are outstanding. There can be little doubt, in spite of the paucity of survivals, that fine decorative objects of ivory were made at all periods. A gazelle and a grasshopper of the 18th dynasty (Metropolitan Museum of Art and Brooklyn Museum) may truly be described as *objets de vertu*. Many fine examples of the use of ivory were found in Tutankhamen's tomb, from simple geometric marquetry patterns to box panels carved with exquisitely informal scenes of the king with his queen.

Greco-Roman Egypt

After the conquest of Egypt by Alexander the Great, the independent rule of Pharaohs in the strict sense came to an end. Under the Ptolemies, whose rule followed Alexander's, profound changes took place in art and architecture.

The most lasting impression of the new period is made by the architectural legacy. Although very little survives of important funerary architecture, there is a group of tombs at Tunah al-Jabal of unusual form and great importance. Most interesting is the tomb of Petosiris, high priest of Thoth in nearby Hermopolis Magna in the late 4th century BC. It is in the form of a small temple with pillared portico, elaborate column capitals, and a large forecourt. In its mural decorations a strong Greek influence merges with the traditional Egyptian modes of expression.

Ptolemaic temples

A boom in temple building of a more conventional kind followed the establishment of the Ptolemaic regime. At Dandarah, Esna, Idfū, Kawm Umbū (Kōm Ombo), and

Philae the Egyptian cult temple can be studied better than at almost any earlier temple. The temple of Horus at Idfū is the most complete, displaying all the essentials of the classical Egyptian temple. The common judgment on these late temples is adverse, but for exploitation of setting and richness of detail it is difficult to fault the temples of Philae and Kawm Umbū, in particular.

In relief carving a noticeable change had taken place in the conventional proportions of human figures during the Saite Period, and subsequently, with added influences from Greek art, a more voluptuous style of human representation developed. There is also undoubtedly some coarseness in much of the new work. Nevertheless, there is much to admire in the best reliefs of the Hathor Temple at Dandarah and in the double cult temple of Sebek and Horus at Kawm Umbū.

Generous representation of the human form, especially the female form, also characterizes the sculpture of the Ptolemaic Period, and there is little to match the figure of Queen Arsinoe II (State Hermitage Museum, Leningrad). It is in the treatment of the head, however, that the greatest changes took place. It is a matter of debate whether the new emphasis on portraiture was attributable to influences from the classical world or was a development of earlier Egyptian sculptural tendencies. Fine pieces such as the schist "green" head of a man (Ägyptisches Museum) could not have failed to impress the observer from the Ptolemaic court or the later Roman administration. One of the finest surviving heads, in diorite, slightly larger than life-size and of dominating appearance, is the "black" head in The Brooklyn Museum (Figure 9).



Figure 9: Black diorite head of a high official, possibly a high priest of Ptah of Memphis, Ptolemaic Period (c. 75 BC). In The Brooklyn Museum. Height 41.4 cm.

By courtesy of The Brooklyn Museum, gift of the Charles Edwin Wilbour Fund

Throughout the Ptolemaic Period votive sculpture of private persons was made in great quantity. After the Roman conquest it became rare and of indifferent quality. Such Egyptian art as can be isolated in the Roman Period is found in funerary equipment—in coffins, shrouds, and panel portraits. A mixture of Egyptian and classical styles and of diverse symbolisms can be observed. The great shroud showing the deceased and his mummy protected by the mortuary deity, Anubis (Louvre), while harking back to the traditions of pharaonic Egypt, also displays in the figure of the deceased a style that points to Byzantium.

Mummy portraits

The mummy, or Fayum, portraits are Egyptian only in that they are associated with essentially Egyptian burial customs. Painted in an encaustic technique, they represent mostly Greek inhabitants of Egypt. Seen properly in context, as in the complete mummy of Artemidorus (British Museum), they provide a strange epilogue to the funerary art of 3,000 years of pharaonic Egypt. In this field and in a few others the vigour of the native tradition persisted artistically up to the Roman conquest. Thereafter the decline was rapid and complete. By the 3rd century AD Egypt was on the way to becoming a Christian country. The old tradition was not only destroyed, it was no longer valued. Coptic art was to find its inspiration elsewhere.

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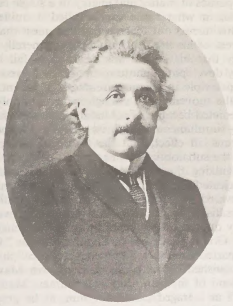
(T.G.H.J.)

Einstein

Recognized in his own time as one of the most creative intellects in human history, Albert Einstein, in the first 15 years of the 20th century, advanced a series of theories that for the first time asserted the equivalence of mass and energy and proposed entirely new ways of thinking about space, time, and gravitation. His theories of relativity and gravitation were a profound advance over the old Newtonian physics and revolutionized scientific and philosophic inquiry.

Herein lay the unique drama of Einstein's life. He was a self-confessed lone traveller; his mind and heart soared with the cosmos, yet he could not armour himself against the intrusion of the often horrendous events of the human community. Almost reluctantly he admitted that he had a "passionate sense of social justice and social responsibility." His celebrity gave him an influential voice that he used to champion such causes as pacifism, liberalism, and Zionism. The irony for this idealistic man was that his famous postulation of an energy–mass equation, which states that a particle of matter can be converted into an enormous quantity of energy, had its spectacular proof in the creation of the atomic and hydrogen bombs, the most destructive weapons ever known.



Einstein.

By courtesy of the Nobelstiftelsen, Stockholm

Early life and career. Albert Einstein was born in Ulm, Germany, on March 14, 1879. The following year his family moved to Munich, where Hermann Einstein, his father, and Jakob Einstein, his uncle, set up a small electrical plant and engineering works. In Munich Einstein attended rigidly disciplined schools. Under the harsh and pedantic regimentation of 19th-century German education, which he found intimidating and boring, he showed little scholastic ability. At the behest of his mother, Einstein also studied music; though throughout life he played exclusively for relaxation, he became an accomplished violinist. It was then only Uncle Jakob who stimulated in Einstein a fascination for mathematics and Uncle Cäsar Koch who stimulated a consuming curiosity about science.

By the age of 12 Einstein had decided to devote himself to solving the riddle of the "huge world." Three years later, with poor grades in history, geography, and languages, he left school with no diploma and went to Milan to rejoin his family, who had recently moved there from Germany because of his father's business setbacks. Albert Einstein resumed his education in Switzerland, culminating in four years of physics and mathematics at the renowned Federal Polytechnic Academy in Zürich.

After his graduation in the spring of 1900, he became a Swiss citizen, worked for two months as a mathematics teacher, and then was employed as examiner at the Swiss patent office in Bern. With his newfound security, Einstein married his university sweetheart, Mileva Marić, in 1903.

First contributions to science

Early in 1905 Einstein published in the prestigious German physics monthly *Annalen der Physik* a thesis, "A New Determination of Molecular Dimensions," that won him a Ph.D. from the University of Zürich. Four more important papers appeared in *Annalen* that year and forever changed man's view of the universe.

The first of these, "Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen" ("On the Motion—Required by the Molecular Kinetic Theory of Heat—of Small Particles Suspended in a Stationary Liquid"), provided a theoretical explanation of Brownian motion. In "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt" ("On a Heuristic Viewpoint Concerning the Production and Transformation of Light"), Einstein postulated that light is composed of individual quanta (later called photons) that, in addition to wavelike behaviour, demonstrate certain properties unique to particles. In a single stroke he thus revolutionized the theory of light and provided an explanation for, among other phenomena, the emission of electrons from some solids when struck by light, called the photoelectric effect.

Einstein's special theory of relativity, first printed in "Zur Elektrodynamik bewegter Körper" ("On the Electrodynamics of Moving Bodies"), had its beginnings in an essay Einstein wrote at age 16. The precise influence of work by other physicists on Einstein's special theory is still controversial. The theory held that, if, for all frames of reference, the speed of light is constant and if all natural laws are the same, then both time and motion are found to be relative to the observer.

In the mathematical progression of the theory, Einstein published his fourth paper, "Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?" ("Does the Inertia of a Body Depend Upon Its Energy Content?"). This mathematical footnote to the special theory of relativity established the equivalence of mass and energy, according to which the energy E of a quantity of matter, with mass m, is equal to the product of the mass and the square of the velocity of light, c. This relationship is commonly expressed in the form $E = mc^2$.

Public understanding of this new theory and acclaim for its creator were still many years off, but Einstein had won a place among Europe's most eminent physicists, who increasingly sought his counsel, as he did theirs. While Einstein continued to develop his theory, attempting now to encompass with it the phenomenon of gravitation, he left the patent office and returned to teaching—first in Switzerland, briefly at the German University in Prague, where he was awarded a full professorship, and then, in the winter of 1912, back at the Polytechnic in Zürich. He was later remembered from this time as a very happy man, content in his marriage and delighted with his two young sons, Hans Albert and Edward.

In April 1914 the family moved to Berlin, where Einstein had accepted a position with the Prussian Academy of Sciences, an arrangement that permitted him to continue his researches with only the occasional diversion of lecturing at the University of Berlin. His wife and two sons vacationed in Switzerland that summer and, with the eruption of World War I, were unable to return to Berlin. A few years later this enforced separation was to lead to divorce. Einstein abhorred the war and was an outspoken critic of German militarism among the generally acquiescent academic community in Berlin, but he

General theory of relativity

was primarily engrossed in perfecting his general theory of relativity, which he published in *Annalen der Physik* as "Die Grundlagen der allgemeinen Relativitätstheorie" ("The Foundation of the General Theory of Relativity") in 1916. The heart of this postulate was that gravitation is not a force, as Newton had said, but a curved field in the space–time continuum, created by the presence of mass. This notion could be proved or disproved, he suggested, by measuring the deflection of starlight as it travelled close by the Sun, the starlight being visible only during a total eclipse. Einstein predicted twice the light deflection that would be accountable under Newton's laws.

His new equations also explained for the first time the puzzling irregularity—that is, the slight advance—in the planet Mercury's perihelion, and they demonstrated why stars in a strong gravitational field emitted light closer to the red end of the spectrum than those in a weaker field.

While Einstein awaited the end of the war and the opportunity for his theory to be tested under eclipse conditions, he became more and more committed to pacifism, even to the extent of distributing pacifist literature to sympathizers in Berlin. His attitudes were greatly influenced by the French pacifist and author Romain Rolland, whom he met on a wartime visit to Switzerland. Rolland's diary later provided the best glimpse of Einstein's physical appearance as he reached his middle 30s:

> Einstein is still a young man, not very tall, with a wide and long face, and a great mane of crispy, frizzled and very black hair, sprinkled with gray and rising high from a lofty brow. His nose is fleshy and prominent, his mouth small, his lips full, his cheeks plump, his chin rounded. He wears a small cropped mustache. (By permission of Madame Marie Romain Rolland.)

Einstein's view of humanity during the war period appears in a letter to his friend, the Austrian-born Dutch physicist Paul Ehrenfest:

> The ancient Jehovah is still abroad. Alas, he slays the innocent along with the guilty, whom he strikes so fearsomely blind that they can feel no sense of guilt. . . . We are dealing with an epidemic delusion which, having caused infinite suffering, will one day vanish and become a monstrous and incomprehensible source of wonderment to later generations. (From Otto Nathan and Heinz Norden [eds.], *Einstein on Peace;* Simon and Schuster, 1960.)

It would be said often of Einstein that he was naïve about human affairs; for example, with the proclamation of the German Republic and the armistice in 1918, he was convinced that militarism had been thoroughly abolished in Germany.

International acclaim. International fame came to Einstein in November 1919, when the Royal Society of London announced that its scientific expedition to Príncipe Island, in the Gulf of Guinea, had photographed the solar eclipse on May 29 of that year and completed calculations that verified the predictions made in Einstein's general theory of relativity. Few could understand relativity, but the basic postulates were so revolutionary and the scientific community was so obviously bedazzled that the physicist was acclaimed the greatest genius on Earth. Einstein himself was amazed at the reaction and apparently displeased, for he resented the consequent interruptions of his work. After his divorce he had, in the summer of 1919, married Elsa, the widowed daughter of his late father's cousin. He lived quietly with Elsa and her two daughters in Berlin, but, inevitably, his views as a foremost savant were sought on a variety of issues.

Proof of the general theory of relativity

Despite the now deteriorating political situation in Germany, Einstein attacked nationalism and promoted pacifist ideals. With the rising tide of anti-Semitism in Berlin, Einstein was castigated for his "Bolshevism in physics," and the fury against him in right-wing circles grew when he began publicly to support the Zionist movement. Judaism had played little part in his life, but he insisted that, as a snail can shed his shell and still be a snail, so a Jew can shed his faith and still be a Jew.

Although Einstein was regarded warily in Berlin, such was the demand for him in other European cities that he travelled widely to lecture on relativity, usually arriving at each place by third-class rail carriage, with a violin tucked under his arm. So successful were his lectures that one enthusiastic impresario guaranteed him a three-week booking at the London Palladium. He ignored the offer, but, at the request of the Zionist leader Chaim Weizmann, toured the United States in the spring of 1921 to raise money for the Palestine Foundation Fund. Frequently treated like a circus freak and feted from morning to night, Einstein nevertheless was gratified by the standards of scientific research and the "idealistic attitudes" that he found prevailing in the United States.

During the next three years Einstein was constantly on the move, journeying not only to European capitals but also to the Orient, to the Middle East, and to South America. According to his diary notes, he found nobility among the Hindus of Ceylon, a pureness of soul among the Japanese, and a magnificent intellectual and moral calibre among the Jewish settlers in Palestine. His wife later wrote that, on steaming into one new harbour, Einstein had said to her, "Let us take it all in before we wake up."

The Nobel Prize

In Shanghai a cable reached him announcing that he had been awarded the 1921 Nobel Prize for Physics "for your photoelectric law and your work in the field of theoretical physics." Relativity, still the centre of controversy, was not mentioned.

Though the 1920s were tumultuous times of wide acclaim, and some notoriety, Einstein did not waver from his new search—to find the mathematical relationship between electromagnetism and gravitation. This would be a first step, he felt, in discovering the common laws governing the behaviour of everything in the universe, from the electron to the planets. He sought to relate the universal properties of matter and energy in a single equation or formula, in what came to be called a unified field theory. This turned out to be a fruitless quest that occupied the rest of his life. Einstein's peers generally agreed quite early that his search was destined to fail because the rapidly developing quantum theory uncovered an uncertainty principle in all measurements of the motion of particles: the movement of a single particle simply could not be predicted because of a fundamental uncertainty in measuring simultaneously both its speed and its position, which means, in effect, that the future of any physical system at the subatomic level cannot be predicted. While fully recognizing the brilliance of quantum mechanics, Einstein rejected the idea that these theories were absolute and persevered with his theory of general relativity as the more satisfactory foundation to future discovery. He was widely quoted on his belief in an exactly engineered universe: "God is subtle but he is not malicious." On this point, he parted company with most theoretical physicists. The distinguished German quantum theorist Max Born, a close friend of Einstein, said at the time: "Many of us regard this as a tragedy, both for him, as he gropes his way in loneliness, and for us, who miss our leader and standard-bearer." This appraisal, and others pronouncing his work in later life as largely wasted effort, will have to await the judgment of later generations.

The year of Einstein's 50th birthday, 1929, marked the beginning of the ebb flow of his life's work in a number of aspects. Early in the year the Prussian Academy published the first version of his unified-field theory, but, despite the sensation it caused, its very preliminary nature soon became apparent. The reception of the theory left him undaunted, but Einstein was dismayed by the preludes to certain disaster in the field of human affairs: Arabs launched savage attacks on Jewish colonists in Palestine; the Nazis gained strength in Germany; the League of Nations proved so impotent that Einstein resigned abruptly from its Committee on Intellectual Cooperation as a protest to its timidity; and the stock market crash in New York City heralded worldwide economic crisis.

Crushing Einstein's natural gaiety more than any of these events was the mental breakdown of his younger son, Edward. Edward had worshipped his father from a distance but now blamed him for deserting him and for ruining his life. Einstein's sorrow was eased only slightly by the amicable relationship he enjoyed with his older son, Hans Albert.

As visiting professor at Oxford University in 1931, Ein-

stein spent as much time espousing pacifism as he did discussing science. He went so far as to authorize the establishment of the Einstein War Resisters' International Fund in order to bring massive public pressure to bear on the World Disarmament Conference, scheduled to meet in Geneva in February 1932. When these talks foundered, Einstein felt that his years of supporting world peace and human understanding had accomplished nothing. Bitterly disappointed, he visited Geneva to focus world attention on the "farce" of the disarmament conference. In a rare moment of fury, Einstein stated to a journalist,

Einstein War Resisters' International Fund

> They [the politicians and statesmen] have cheated us. They have fooled us. Hundreds of millions of people in Europe and in America, billions of men and women yet to be born, have been and are being cheated, traded and tricked out of their lives and health and well-being.

Shortly after this, in a famous exchange of letters with the Austrian psychiatrist Sigmund Freud, Einstein suggested that people must have an innate lust for hatred and destruction. Freud agreed, adding that war was biologically sound because of the love–hate instincts of man and that pacifism was an idiosyncrasy directly related to Einstein's high degree of cultural development. This exchange was only one of Einstein's many philosophic dialogues with renowned men of his age. With Rabindranath Tagore, Hindu poet and mystic, he discussed the nature of truth. While Tagore held that truth was realized through man, Einstein maintained that scientific truth must be conceived as a valid truth that is independent of humanity. "I cannot prove that I am right in this, but that is my religion," said Einstein. Firmly denying atheism, Einstein expressed a belief in "Spinoza's God who reveals himself in the harmony of what exists." The physicist's breadth of spirit and depth of enthusiasm were always most evident among truly intellectual men. He loved being with the physicists Paul Ehrenfest and Hendrick A. Lorentz at The Netherlands' Leiden University, and several times he visited the California Institute of Technology in Pasadena to attend seminars at the Mt. Wilson Observatory, which had become world renowned as a centre for astrophysical research. At Mt. Wilson he heard the Belgian scientist Abbé Georges Lemaitre detail his theory that the universe had been created by the explosion of a "primeval atom" and was still expanding. Gleefully, Einstein jumped to his feet, applauding. "This is the most beautiful and satisfactory explanation of creation to which I have ever listened," he said.

In 1933, soon after Adolf Hitler became chancellor of Germany, Einstein renounced his German citizenship and left the country. He later accepted a full-time position as a foundation member of the school of mathematics at the new Institute for Advanced Study in Princeton, New Jersey. In reprisal, Nazi storm troopers ransacked his beloved summer house at Caputh, near Berlin, and confiscated his sailboat. Einstein was so convinced that Nazi Germany was preparing for war that, to the horror of Romain Rolland and his other pacifist friends, he violated his pacifist ideals and urged free Europe to arm and recruit for defense.

Flight from Europe

Although his warnings about war were largely ignored, there were fears for Einstein's life. He was taken by private yacht from Belgium to England. By the time he arrived in Princeton in October 1933, he had noticeably aged. A friend wrote,

> It was as if something had deadened in him. He sat in a chair at our place, twisting his white hair in his fingers and talking dreamily about everything under the sun. He was not laughing any more.

Later years in the United States. In Princeton Einstein set a pattern that was to vary little for more than 20 years. He lived with his wife in a simple, two-story frame house and most mornings walked a mile or so to the Institute, where he worked on his unified field theory and talked with colleagues. For relaxation he played his violin and sailed on a local lake. Only rarely did he travel, even to New York. In a letter to Queen Elisabeth of Belgium, he described his new refuge as a "wonderful little spot, . . . a quaint and ceremonious village of puny demigods on stilts." Eventually he acquired American citizenship, but he always continued to think of himself as a European. Pursuing his own line of theoretical research outside the mainstream of physics, he took on an air of fixed serenity. "Among my European friends, I am now called *Der grosse Schweiger* ("The Great Stone Face"), a title I well deserve," he said. Even his wife's death late in 1936 did not disturb his outward calm. "It seemed that the difference between life and death for Einstein consisted only in the difference between being able and not being able to do physics," wrote Leopold Infeld, the Polish physicist who arrived in Princeton at this time.

Development of the atomic bomb

Niels Bohr, the great Danish atomic physicist, brought news to Einstein in 1939 that the German refugee physicist Lise Meitner had split the uranium atom, with a slight loss of total mass that had been converted into energy. Meitner's experiments, performed in Copenhagen, had been inspired by similar, though less precise, experiments done months earlier in Berlin by two German chemists, Otto Hahn and Fritz Strassmann. Bohr speculated that, if a controlled chain-reaction splitting of uranium atoms could be accomplished, a mammoth explosion would result. Einstein was skeptical, but laboratory experiments in the United States showed the feasibility of the idea. With a European war regarded as imminent and fears that Nazi scientists might build such a "bomb" first, Einstein was persuaded by colleagues to write a letter to President Franklin D. Roosevelt urging "watchfulness and, if necessary, quick action" on the part of the United States in atomic-bomb research. This recommendation marked the beginning of the Manhattan Project.

Although he took no part in the work at Los Alamos, New Mexico, and did not learn that a nuclear-fission bomb had been made until Hiroshima was razed in 1945, Einstein's name was emphatically associated with the advent of the atomic age. He readily joined those scientists seeking ways to prevent any future use of the bomb, his particular and urgent plea being the establishment of a world government under a constitution drafted by the United States, Britain, and Russia. With the spur of the atomic fear that haunted the world, he said "we must not be merely willing, but actively eager to submit ourselves to the binding authority necessary for world security." Once more, Einstein's name surged through the newspapers. Letters and statements tumbled out of his Princeton study, and in the public eye Einstein the physicist dissolved into Einstein the world citizen, a kind "grand old man" devoting his last years to bringing harmony to the world.

The rejection of his ideals by statesmen and politicians did not break him, because his prime obsession still remained with physics. "I cannot tear myself away from my work," he wrote at the time. "It has me inexorably in its clutches." In proof of this came his new version of the unified field in 1950, a most meticulous mathematical essay that was immediately but politely criticized by most physicists as untenable.

New version of the unified field

Compared with his renown of a generation earlier, Einstein was virtually neglected and said himself that he felt almost like a stranger in the world. His health deteriorated to the extent that he could no longer play the violin or sail his boat. Many years earlier, chronic abdominal pains had forced him to give up smoking his pipe and to watch his diet carefully.

On April 18, 1955, Einstein died in his sleep at Princeton Hospital. On his desk lay his last incomplete statement, written to honour Israeli Independence Day. It read in part: "What I seek to accomplish is simply to serve with my feeble capacity truth and justice at the risk of pleasing no one." His contribution to man's understanding of the universe was matchless, and he is established for all time as a giant of science. Broadly speaking, his crusades in human affairs seem to have had no lasting impact. Einstein perhaps anticipated such an assessment of his life when he said, "Politics are for the moment. An equation is for eternity."

(P.M.I.)

MAJOR WORKS

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(P.Mi./Ed.)

Electricity and Magnetism

Electricity and magnetism are two aspects of electromagnetism, the science of charge and of the forces and fields associated with charge. Electricity and magnetism were long thought to be separate forces. It was not until the 19th century that they were finally treated as interrelated phenomena. In 1905 Albert Einstein's special theory of relativity established beyond a doubt that both are aspects of one common phenomenon. At a practical level, however, electric and magnetic forces behave quite differently and are described by different equations. Electric forces are produced by electric charges either at rest or in motion. Magnetic forces, on the other hand, are produced only by moving charges and act solely on charges in motion.

Electric phenomena occur even in neutral matter because the forces act on the individual charged constituents. The electric force, in particular, is responsible for most of the physical and chemical properties of atoms and molecules. It is enormously strong compared with gravity. For example, the absence of only one electron out of every billion molecules in two 70-kilogram (154-pound) persons standing two metres (two yards) apart would repel them with a 30,000-ton force. On a more familiar scale, electric phenomena are responsible for the lightning and thunder accompanying certain storms.

Electric and magnetic forces can be detected in regions called electric and magnetic fields. These fields are fundamental in nature and can exist in space far from the charge or current that generated them. Remarkably, electric fields can produce magnetic fields and vice versa, independent of any external charge. A changing magnetic field produces an electric field, as the English physicist Michael Faraday discovered in work that forms the basis of electric power generation. Conversely, a changing electric field produces a magnetic field, as the Scottish physicist James Clerk Maxwell deduced. The mathematical equations formulated by Maxwell incorporated light and wave phenomena into electromagnetism. He showed that electric and magnetic fields travel together through space as waves of electromagnetic radiation, with the changing fields mutually sustaining each other. Examples of electromagnetic waves traveling through space independent of matter are radio and television waves, microwaves, infrared rays, visible light, ultraviolet light, X rays, and gamma rays. All of these waves travel at the same speed—namely, the velocity of light (roughly 300,000 kilometres, or 186,000 miles, per second). They differ from each other only in the frequency at which their electric and magnetic fields oscillate.

Maxwell's equations still provide a complete and elegant description of electromagnetism down to, but not including, the subatomic scale. The interpretation of his work, however, was broadened in the 20th century. Einstein's special relativity theory merged electric and magnetic fields into one common field and limited the velocity of all matter to the velocity of electromagnetic radiation. During the late 1960s, physicists discovered that other forces in nature have fields with a mathematical structure similar to that of the electromagnetic field. These other forces are the nuclear force, responsible for the energy released in nuclear fusion, and the weak force, observed in the radioactive decay of unstable atomic nuclei. In particular, the weak and electromagnetic forces have been combined into a common force called the electroweak force. The goal of many physicists to unite all of the fundamental forces, including gravity, into one grand unified theory has not been attained to date.

An important aspect of electromagnetism is the science of electricity, which is concerned with the behaviour of aggregates of charge, including the distribution of charge within matter and the motion of charge from place to place. Different types of materials are classified as either conductors or insulators on the basis of whether charges can move freely through their constituent matter. Electric current is the measure of the flow of charges; the laws governing currents in matter are important in technology, particularly in the production, distribution, and control of energy.

The concept of voltage, like those of charge and current, is fundamental to the science of electricity. Voltage is a measure of the propensity of charge to flow from one place to another; positive charges generally tend to move from a region of high voltage to a region of lower voltage. A common problem in electricity is determining the relationship between voltage and current or charge in a given physical situation.

This article seeks to provide a qualitative understanding of electromagnetism as well as a quantitative appreciation for the magnitudes associated with electromagnetic phenomena.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 127 and 128, and the *Index*.

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General considerations

Everyday modern life is pervaded by electromagnetic phenomena. When a light bulb is switched on, a current flows through a thin filament in the bulb; the current heats the filament to such a high temperature that it glows, illuminating its surroundings. Electric clocks and connections link simple devices of this kind into complex systems such as traffic lights that are timed and synchronized with the speed of vehicular flow. Radio and television sets receive information carried by electromagnetic waves traveling through space at the speed of light. To start an automobile, currents in an electric starter motor generate magnetic fields that rotate the motor shaft and drive engine pistons to compress an explosive mixture of gasoline and air; the spark initiating the combustion is an electric discharge, which makes up a momentary current flow.

Many of these devices and phenomena are complex, but they derive from the same fundamental laws of electromagnetism. One of the most important of these is Coulomb's law, which describes the electric force between charged objects. Formulated by the 18th-century French physicist Charles-Augustin de Coulomb, it is analogous to Newton's law for the gravitational force. Both gravitational and electric forces decrease with the square of the distance between the objects, and both forces act along a line between them. In Coulomb's law, however, the magnitude and sign of the electric force are determined by the charge, rather than the mass, of an object. Thus, charge determines how electromagnetism influences the motion of charged objects. (Charge is a basic property of matter. Every constituent of matter has an electric charge with a value that can be positive, negative, or zero. For example, electrons are negatively charged, and atomic nuclei are positively charged. Most bulk matter has an equal amount of positive and negative charge and thus has zero net charge.)

Coulomb's law

According to Coulomb, the electric force for charges at rest has the following properties:

(1) Like charges repel each other; unlike charges attract. Thus, two negative charges repel one another, while a positive charge attracts a negative charge.

(2) The attraction or repulsion acts along the line between the two charges.

(3) The size of the force varies inversely as the square of the distance between the two charges. Therefore, if the distance between the two charges is doubled, the attraction or repulsion becomes weaker, decreasing to one-fourth of the original value. If the charges come 10 times closer, the size of the force increases by a factor of 100.

(4) The size of the force is proportional to the value of each charge. The unit used to measure charge is the coulomb (C). If there were two positive charges, one of 0.1 coulomb and the second of 0.2 coulomb, they would repel each other with a force that depends on the product 0.2×0.1. If each of the charges were reduced by one-half, the repulsion would be reduced to one-quarter of its former value.

Static cling is a practical example of the Coulomb force. In static cling, garments made of synthetic material collect a charge, especially in dry winter air. A plastic or rubber comb passed quickly through hair also becomes charged and will pick up bits of paper. The synthetic fabric and the comb are insulators; charge on these objects cannot move easily from one part of the object to another. Similarly, an office copy machine uses electric force to attract particles of ink to paper.

Like Coulomb's law, the principle of charge conservation is a fundamental law of nature. According to this principle, the charge of an isolated system cannot change. If an additional positively charged particle appears within a system, a particle with a negative charge of the same magnitude will be created at the same time; thus, the principle of conservation of charge is maintained. In nature, a pair of oppositely charged particles is created when high-energy radiation interacts with matter; an electron and a positron are created in a process known as pair production.

Principle of charge conservation

The smallest subdivision of the amount of charge that a particle can have is the charge of one proton, $+1.602 \times 10^{-19}$ coulomb. The electron has a charge of the same magnitude but opposite sign—*i.e.*, -1.602×10^{-19} coulomb. An ordinary flashlight battery delivers a current that provides a total charge flow of approximately 5,000 coulomb, which corresponds to more than 10^{22} electrons, before it is exhausted.

Electric current is a measure of the flow of charge, as, for example, charge flowing through a wire. The size of the current is measured in amperes and symbolized by *i*. An ampere of current represents the passage of one coulomb of charge per second, or 6.2 billion billion electrons (6.2×10^{18} electrons) per second. A current is positive when it is in the direction of the flow of positive charges; its direction is opposite to the flow of negative charges.

The force and conservation laws are only two aspects of electromagnetism, however. Electric and magnetic forces are caused by electromagnetic fields. The term field denotes a property of space, so that the field quantity has a numerical value at each point of space. These values may also vary with time. The value of the electric or magnetic field is a vector—*i.e.*, a quantity having both magnitude and direction. The value of the electric field at a point in space, for example, equals the force that would be exerted on a unit charge at that position in space.

Every charged object sets up an electric field in the surrounding space. A second charge "feels" the presence of this field. The second charge is either attracted toward the initial charge or repelled from it, depending on the signs of the charges. Of course, since the second charge also has an electric field, the first charge feels its presence and is either attracted or repelled by the second charge, too.

Electric fields and forces

The electric field from a charge is directed away from the charge when the charge is positive and toward the charge when it is negative. The electric field from a charge at rest is shown in Figure 1 for various locations in space. The arrows point in the direction of the electric field, and the length of the arrows indicates the strength of the field at the midpoint of the arrows.

If a positive charge were placed in the electric field, it would feel a force in the direction of the field. A negative charge would feel a force in the direction opposite the direction of the field.

In calculations, it is often more convenient to deal directly with the electric field than with the charges; fre-

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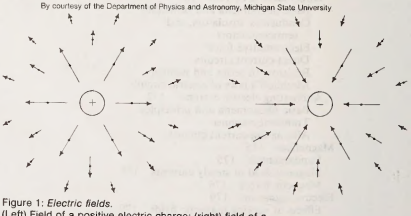

Figure 1: *Electric fields.*
(Left) Field of a positive electric charge; (right) field of a negative electric charge.

quently, more is known about the field than about the distribution of charges in space. For example, the distribution of charges in conductors is generally unknown because the charges move freely within the conductor. In static situations, however, the electric field in a conductor in equilibrium has a definite value, zero, because any force on the charges inside the conductor redistributes them until the field vanishes. The unit of electric field is newtons per coulomb, or volts per metre.

Electric potential

The electric potential is another useful field. It provides an alternative to the electric field in electrostatics problems. The potential is easier to use, however, because it is a single number, a scalar, instead of a vector. The difference in potential between two places measures the degree to which charges are influenced to move from one place to another. If the potential is the same at two places (*i.e.*, if the places have the same voltage), charges will not be influenced to move from one place to the other. The potential on an object or at some point in space is measured in volts; it equals the electrostatic energy that a unit charge would have at that position. In a typical 12-volt car battery, the battery terminal that is marked with a + sign is at a potential 12 volts greater than the potential of the terminal marked with the − sign. When a wire, such as the filament of a car headlight, is connected between the + and the − terminals of the battery, charges move through the filament as an electric current and heat the filament; the hot filament radiates light.

Magnetic fields and forces

The magnetic force influences only those charges that are already in motion. It is transmitted by the magnetic field. Both magnetic fields and magnetic forces are more complicated than electric fields and electric forces. The magnetic field does not point along the direction of the source of the field; instead, it points in a perpendicular direction. In addition, the magnetic force acts in a direction that is perpendicular to the direction of the field. In comparison, both the electric force and the electric field point directly toward or away from the charge.

The present discussion will deal with simple situations in which the magnetic field is produced by a current of charge in a wire. Certain materials, such as copper, silver, and aluminum, are conductors that allow charge to flow freely from place to place. If an external influence establishes a current in a conductor, the current generates a magnetic field. For a long straight wire, the magnetic field has a direction that encircles the wire on a plane perpendicular to the wire. The strength of the magnetic field decreases with distance from the wire. The arrows in Figure 2 represent the size and direction of the magnetic field for a current moving in the direction indicated. Figure 2A shows an end view with the current coming toward the reader, while Figure 2B provides a three-dimensional view of the magnetic field at one position along the wire.

In subsequent figures, continuous lines will be used to represent the direction of electric and magnetic fields. These lines emphasize the important fact that electric fields begin on positive charges and end on negative charges, while magnetic fields do not have beginnings or ends and close on themselves. The magnetic field shown in Figure 2

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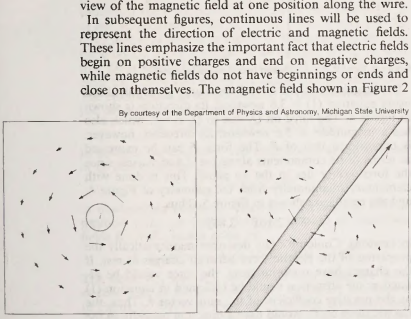

Figure 2: *Magnetic field of a long wire.*
(A) An end view, with the current flowing toward the reader.
(B) A three-dimensional view.

is unusually simple. Highly complex and useful magnetic fields can be generated by the proper choice of conductors to carry electric currents. Under development are thermonuclear fusion reactors for obtaining energy from the fusion of light nuclei in the form of very hot plasmas of hydrogen isotopes. The plasmas have to be confined by magnetic fields (dubbed "magnetic bottles") as no material container can withstand such high temperatures. Charged particles are also confined by magnetic fields in nature. Large numbers of charged particles, mostly protons and electrons, are trapped in huge bands around the Earth by its magnetic field. These bands are known as the Van Allen radiation belts. Disturbance of the Earth's confining magnetic field produces spectacular displays, the so-called northern lights, in which trapped charged particles are freed and crash through the atmosphere to Earth.

How does the magnetic field interact with a charged object? If the charge is at rest, there is no interaction. If the charge moves, however, it is subjected to a force, the size of which increases in direct proportion with the velocity of the charge. The force has a direction that is perpendicular both to the direction of motion of the charge and to the direction of the magnetic field. There are two possible precisely opposite directions for such a force for a given direction of motion. This apparent ambiguity is resolved by the fact that one of the two directions applies to the force on a moving positive charge while the other direction applies to the force on a moving negative charge. Figure 3 illustrates the directions of the magnetic force on positive charges and on negative charges as they move in a magnetic field that is perpendicular to the motion.

Interaction of a magnetic field with charge

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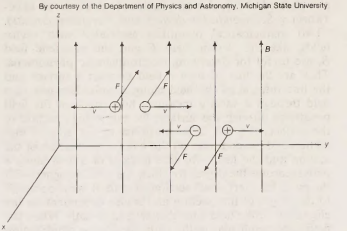

Figure 3: *Magnetic force on moving charges.*
The magnetic force *F* is proportional to the charge and to the magnitude of velocity *v* times the magnetic field *B*.

Depending on the initial orientation of the particle velocity to the magnetic field, charges having a constant speed in a uniform magnetic field will follow a circular or helical path.

Electric currents in wires are not the only source of magnetic fields. Naturally occurring minerals exhibit magnetic properties and have magnetic fields. These magnetic fields result from the motion of electrons in the atoms of the material. They also result from a property of electrons called the magnetic dipole moment, which is related to the intrinsic spin of individual electrons (see the article ATOMS: *Electrons*). In most materials, little or no field is observed outside the matter because of the random orientation of the various constituent atoms. In some materials such as iron, however, atoms within certain distances tend to become aligned in one particular direction.

Magnets have numerous applications, ranging from use as toys and paper holders on home refrigerators to essential components in electric generators and machines that can accelerate particles to speeds approaching that of light. The practical application of magnetism in technology is greatly enhanced by using iron and other ferromagnetic materials with electric currents in devices like motors. These materials amplify the magnetic field produced by the currents and thereby create more powerful fields (see below *Ferromagnetism*).

While electric and magnetic effects are well separated in many phenomena and applications, they are coupled

Time-varying magnetic field

closely together when there are rapid time fluctuations. Faraday's law of induction describes how a time-varying magnetic field produces an electric field (see below *Faraday's law of induction*). Important practical applications include the electric generator and transformer. In a generator, the physical motion of a magnetic field produces electricity for power. In a transformer, electric power is converted from one voltage level to another by the magnetic field of one circuit inducing an electric current in another circuit.

The existence of electromagnetic waves depends on the interaction between electric and magnetic fields. Maxwell postulated that a time-varying electric field produces a magnetic field. His theory predicted the existence of electromagnetic waves in which each time-varying field produces the other field. For example, radio waves are generated by electronic circuits known as oscillators that cause rapidly oscillating currents to flow in antennas; the rapidly varying magnetic field has an associated varying electric field. The result is the emission of radio waves into space (see ELECTROMAGNETIC RADIATION).

Many electromagnetic devices can be described by circuits consisting of conductors and other elements. These circuits may operate with a steady flow of current, as in a flashlight, or with time-varying currents. Important elements in circuits include sources of power called electromotive forces; resistors, which control the flow of current for a given voltage; capacitors, which store charge and energy temporarily; and inductors, which also store electrical energy for a limited time. Circuits with these elements can be described entirely with algebra. (For more complicated circuit elements such as transistors, see ELECTRONICS: *Semiconductor devices* and *Integrated circuits*).

Fluxes and line integrals of vector fields

Two mathematical quantities associated with vector fields, like the electric field E and the magnetic field B, are useful for describing electromagnetic phenomena. They are the flux of such a field through a surface and the line integral of the field along a path. The flux of a field through a surface measures how much of the field penetrates through the surface; for every small section of the surface, the flux is proportional to the area of that section and depends also on the relative orientation of the section and the field. The line integral of a field along a path measures the degree to which the field is aligned with the path; for every small section of path, it is proportional to the length of that section and is also dependent on the alignment of the field with that section of path. When the field is perpendicular to the path, there is no contribution to the line integral. The fluxes of E and B through a surface and the line integrals of these fields along a path play an important role in electromagnetic theory. As examples, the flux of the electric field E through a closed surface measures the amount of charge contained within the surface; the flux of the magnetic field B through a closed surface is always zero because there are no magnetic monopoles (magnetic charges consisting of a single pole) to act as sources of the magnetic field in the way that charge is a source of the electric field.

Electricity

ELECTROSTATICS

Use of mathematical methods

Electrostatics is the study of electromagnetic phenomena that occur when there are no moving charges—*i.e.*, after a static equilibrium has been established. Charges reach their equilibrium positions rapidly because the electric force is extremely strong. The mathematical methods of electrostatics make it possible to calculate the distributions of the electric field and of the electric potential from a known configuration of charges, conductors, and insulators. Conversely, given a set of conductors with known potentials, it is possible to calculate electric fields in regions between the conductors and to determine the charge distribution on the surface of the conductors. The electric energy of a set of charges at rest can be viewed from the standpoint of the work required to assemble the charges; alternatively, the energy also can be considered to reside in the electric field produced by this assembly of charges. Finally, energy can be stored in a capacitor; the energy required to charge such a device is stored in it as electrostatic energy of the electric field.

Static electricity. This is a familiar electric phenomenon in which friction transfers charged particles from one body to another. If two objects are rubbed together, especially if the objects are insulators and the surrounding air is dry, the objects acquire equal and opposite charges and an attractive force develops between them. The object that loses electrons becomes positively charged, and the other becomes negatively charged. The force is simply the attraction between charges of opposite sign. The properties of this force were described above; they are incorporated in the mathematical relationship known as Coulomb's law. The electric force on a charge Q_1 under these conditions, due to a charge Q_2 at a distance r, is given by Coulomb's law,

$$F = k\frac{Q_1 Q_2}{r^2}\hat{r}. \qquad (1)$$

The bold characters in the equation indicate the vector nature of the force, and the unit vector $\hat{r}$ is a vector that has a size of one and that points from charge Q_2 to charge Q_1. The proportionality constant k equals $10^{-7}c^2$, where c is the speed of light in a vacuum; k has the numerical value of 8.99×10^9 newtons-square metre per coulomb squared (Nm^2/C^2). Figure 4 shows the force on Q_1 due to Q_2. A numerical example will help to illustrate this force. Both Q_1 and Q_2 are chosen arbitrarily to be positive charges, each with a magnitude of 10^{-6} coulomb. The charge Q_1 is located at coordinates x, y, z with values of 0.03, 0, 0, respectively, while Q_2 has coordinates 0, 0.04, 0. All coordinates are given in metres. Thus, the distance between Q_1 and Q_2 is 0.05 metre.

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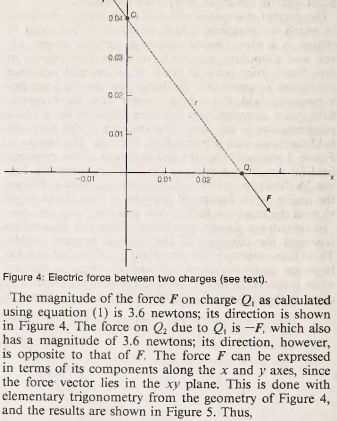

Figure 4: Electric force between two charges (see text).

The magnitude of the force F on charge Q_1 as calculated using equation (1) is 3.6 newtons; its direction is shown in Figure 4. The force on Q_2 due to Q_1 is $-F$, which also has a magnitude of 3.6 newtons; its direction, however, is opposite to that of F. The force F can be expressed in terms of its components along the x and y axes, since the force vector lies in the xy plane. This is done with elementary trigonometry from the geometry of Figure 4, and the results are shown in Figure 5. Thus,

$$F = 2.16\hat{x} - 2.88\hat{y} \qquad (2)$$

in newtons. Coulomb's law describes mathematically the properties of the electric force between charges at rest. If the charges have opposite signs, the force would be attractive; the attraction would be indicated in equation (1) by the negative coefficient of the unit vector $\hat{r}$. Thus, the electric force on Q_1 would have a direction opposite to the unit vector $\hat{r}$ and would point from Q_1 to Q_2. In Cartesian coordinates, this would result in a change of the signs of both the x and y components of the force in equation (2).

How can this electric force on Q_1 be understood? Fun-

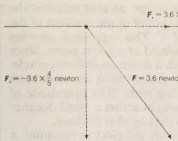

Figure 5: The *x* and *y* components of the force *F* in Figure 4 (see text).

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damentally, the force is due to the presence of an electric field at the position of Q_1. The field is caused by the second charge Q_2 and has a magnitude proportional to the size of Q_2. In interacting with this field, the first charge some distance away is either attracted to or repelled from the second charge, depending on the sign of the first charge.

Calculating the value of an electric field

In the example, the charge Q_1 is in the electric field produced by the charge Q_2. This field has the value

$$E = k\frac{Q_2}{r^2}\hat{r} \tag{3}$$

in newtons per coulomb (N/C). (Electric field can also be expressed in volts per metre [V/m], which is the equivalent of newtons per coulomb.) The electric force on Q_1 is given by

$$F = Q_1 E \tag{4}$$

in newtons. This equation can be used to define the electric field of a point charge. The electric field E produced by charge Q_2 is a vector. The magnitude of the field varies inversely as the square of the distance from Q_2; its direction is away from Q_2 when Q_2 is a positive charge and toward Q_2 when Q_2 is a negative charge. Using equations (2) and (4), the field produced by Q_2 at the position of Q_1 is

$$E = 2.16 \times 10^6\hat{x} - 2.88 \times 10^6\hat{y}$$

in newtons per coulomb.

When there are several charges present, the force on a given charge Q_1 may be simply calculated as the sum of the individual forces due to the other charges Q_2, Q_3, . . . , etc., until all the charges are included. This sum requires that special attention be given to the direction of the individual forces since forces are vectors. The force on Q_1 can be obtained with the same amount of effort by first calculating the electric field at the position of Q_1 due to Q_2, Q_3, . . . , etc. To illustrate this, a third charge is added to the example above. There are now three charges, $Q_1 = +10^{-6}$ C, $Q_2 = +10^{-6}$ C, and $Q_3 = -10^{-6}$ C. The locations of the charges, using Cartesian coordinates [*x*, *y*, *z*] are, respectively, [0.03, 0, 0], [0, 0.04, 0], and [−0.02, 0, 0] metre, as shown in Figure 6. The goal is to find the force on Q_1. From the sign of the charges, it can be seen that Q_1 is repelled by Q_2 and attracted by Q_3. It is also clear that these two forces act along different directions. The electric field at the position of Q_1 due to charge Q_2 is, just as in the example above,

$$E_{1,2} = 2.16 \times 10^6\hat{x} - 2.88 \times 10^6\hat{y}$$

in newtons per coulomb. The electric field at the location of Q_1 due to charge Q_3 is

$$E_{1,3} = -3.6 \times 10^6\hat{x}$$

in newtons per coulomb. Thus, the total electric field at position 1 (*i.e.*, at [0.03, 0, 0]) is the sum of these two fields $E_{1,2} + E_{1,3}$ and is given by

$$E_1\,(total) = -1.44 \times 10^6\hat{x} - 2.88 \times 10^6\hat{y}.$$

The fields $E_{1,2}$ and $E_{1,3}$, as well as their sum, the total electric field at the location of Q_1, $E_1\,(total)$, are shown in Figure 6. The total force on Q_1 is then obtained from equation (4) by multiplying the electric field $E_1\,(total)$ by Q_1. In Cartesian coordinates, this force, expressed in newtons, is given by its components along the *x* and *y* axes by

$$F_1\,(total) = -1.44\hat{x} - 2.88\hat{y}.$$

The resulting force on Q_1 is in the direction of the total electric field at Q_1, shown in Figure 6. The magnitude of the force, which is obtained as the square root of the sum of the squares of the components of the force given in the above equation, equals 3.22 newtons.

This calculation demonstrates an important property of the electromagnetic field known as the superposition principle. According to this principle, a field arising from a number of sources is determined by adding the individual fields from each source. The principle is illustrated by Figure 6, in which an electric field arising from several sources is determined by the superposition of the fields from each of the sources. In this case, the electric field at the location of Q_1 is the sum of the fields due to Q_2 and Q_3. Studies of electric fields over an extremely wide range of magnitudes have established the validity of the superposition principle.

Superposition principle

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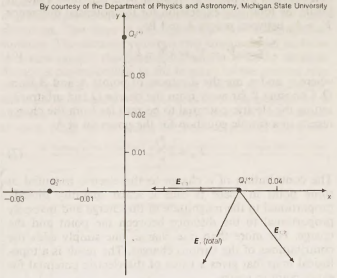

Figure 6: Electric field at the location of Q_1 (see text).

The vector nature of an electric field produced by a set of charges introduces a significant complexity. Specifying the field at each point in space requires giving both the magnitude and the direction at each location. In the Cartesian coordinate system, this necessitates knowing the magnitude of the *x*, *y*, and *z* components of the electric field at each point in space. It would be much simpler if the value of the electric field vector at any point in space could be derived from a scalar function with magnitude and sign.

The electric potential is just such a scalar function. Electric potential is related to the work done by an external force when it transports a charge slowly from one position to another in an environment containing other charges at rest. The difference between the potential at point A and the potential at point B is defined by the equation

$$V_A - V_B = \frac{\text{work to move charge } q \text{ from B to A}}{q}. \tag{5}$$

As noted above, electric potential is measured in volts. Since work is measured in joules in the Système Internationale d'Unités (SI), one volt is equivalent to one joule per coulomb. The charge q is taken as a small test charge; it is assumed that the test charge does not disturb the distribution of the remaining charges during its transport from point B to point A.

To illustrate the work in equation (5), Figure 7 shows a positive charge $+Q$. Consider the work involved in moving a second charge q from B to A. Along path 1, work is done to offset the electric repulsion between the two charges. If path 2 is chosen instead, no work is done in moving q from B to C, since the motion is perpendicular to the electric force; moving q from C to D, the work is, by symmetry, identical as from B to A, and no work is required from D to A. Thus, the total work done in moving q from B to A is the same for either path. It can be shown easily that the same is true for any path going from B to A. When the initial and final positions of the charge q are located on a sphere centred on the location of the $+Q$ charge, no work is done; the electric potential at the initial position has the same value as at the final position. The

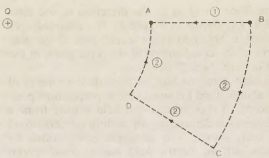

Figure 7: Positive charge $+Q$ and two paths in moving a second charge, q, from B to A (see text).
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sphere in this example is called an equipotential surface. When equation (5), which defines the potential difference between two points, is combined with Coulomb's law, it yields the following expression for the potential difference $V_A - V_B$ between points A and B:

$$V_A - V_B = k\frac{Q}{r_a} - k\frac{Q}{r_b}, \tag{6}$$

where r_a and r_b are the distances of points A and B from Q. Choosing B far away from the charge Q and arbitrarily setting the electric potential to be zero far from the charge results in a simple equation for the potential at A:

$$V_A = k\frac{Q}{r_a}. \tag{7}$$

The contribution of a charge to the electric potential at some point in space is thus a scalar quantity directly proportional to the magnitude of the charge and inversely proportional to the distance between the point and the charge. For more than one charge, one simply adds the contributions of the various charges. The result is a topological map that gives a value of the electric potential for every point in space.

Figure 8 provides three-dimensional views illustrating the effect of the positive charge $+Q$ located at the origin on either a second positive charge q (Figure 8A) or on a negative charge $-q$ (Figure 8B); the potential energy "landscape" is illustrated in each case. The potential energy of a charge q is the product qV of the charge and of the electric potential at the position of the charge. In Figure 8A, the positive charge q would have to be pushed by some external agent in order to get close to the location of $+Q$ because, as q approaches, it is subjected to an increasingly repulsive electric force. For the negative charge $-q$, the potential energy in Figure 8B shows, instead of a steep hill, a deep funnel. The electric potential due to $+Q$ is still positive, but the potential energy is negative, and the negative charge $-q$, in a manner quite analogous to a particle under the influence of gravity, is attracted toward the origin where charge $+Q$ is located.

The electric field is related to the variation of the electric potential in space. The potential provides a convenient tool for solving a wide variety of problems in electrostatics. In a region of space where the potential varies, a charge is subjected to an electric force. For a positive charge the direction of this force is opposite the gradient of the potential—that is to say, in the direction in which the potential decreases the most rapidly. A negative charge would be subjected to a force in the direction of the most rapid increase of the potential. In both instances, the magnitude of the force is proportional to the rate of change of the potential in the indicated directions. If the potential in a region of space is constant, there is no force on either positive or negative charge. In a 12-volt car battery, positive charges would tend to move away from the positive terminal and toward the negative terminal, while negative charges would tend to move in the opposite direction—*i.e.*, from the negative to the positive terminal. The latter occurs when a copper wire, in which there are electrons that are free to move, is connected between the two terminals of the battery.

The electric field has already been described in terms of the force on a charge. If the electric potential is known at every point in a region of space, the electric field can be derived from the potential. In vector calculus notation, the electric field is given by the negative of the gradient of the electric potential, $E = -\mathbf{grad}\ V$. This expression specifies how the electric field is calculated at a given point. Since the field is a vector, it has both a direction and magnitude. The direction is that in which the potential decreases most rapidly, moving away from the point. The magnitude of the field is the change in potential across a small distance in the indicated direction divided by that distance.

Deriving electric field from potential

To become more familiar with the electric potential, a numerically determined solution is presented for a two-dimensional configuration of electrodes. A long, circular conducting rod is maintained at an electric potential of -20 volts. Next to the rod, a long L-shaped bracket, also made of conducting material, is maintained at a potential of $+20$ volts. Both the rod and bracket are placed inside a long, hollow metal tube with a square cross section; this enclosure is at a potential of zero (*i.e.*, it is at "ground" potential). Figure 9 shows the geometry of the problem. Because the situation is static, there is no electric field inside the material of the conductors. If there were such a field, the charges that are free to move in a conducting material would do so until equilibrium was reached. The

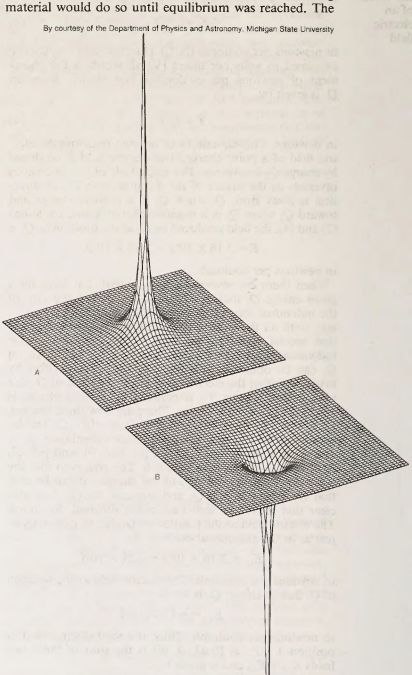

Figure 8: *Potential energy landscape.*
(A) Potential energy of a positive charge near a second positive charge. (B) Potential energy of a negative charge near a positive charge (see text).

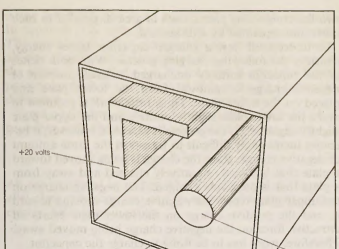

Figure 9: *Electrode configuration.*
A circular conducting rod is maintained at a potential of −20 volts, while an L-shaped bracket of conducting material is maintained at a potential of +20 volts. The electrodes are enclosed in a metal tube, which is at a potential of zero (see text).
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charges are arranged so that their individual contributions to the electric field at points inside the conducting material add up to zero. In a situation of static equilibrium, excess charges are located on the surface of conductors. Because there are no electric fields inside the conducting material, all parts of a given conductor are at the same potential; hence, a conductor is an equipotential in a static situation.

In Figure 10, the numerical solution of the problem gives the potential at a large number of points inside the cavity. The locations of the +20-volt and −20-volt electrodes can be recognized easily. In carrying out the numerical solution of the electrostatic problem in the figure, the electrostatic potential was determined directly by means of one of its important properties: in a region where there is no charge (in this case, between the conductors), the value of the potential at a given point is the average of the values of the potential in the neighbourhood of the point. This follows from the fact that the electrostatic potential in a charge-free region obeys Laplace's equation, which in vector calculus notation is *div* **grad** $V = 0$. This equation is a special case of Poisson's equation *div* **grad** $V = \rho$, which is applicable to electrostatic problems in regions where the volume charge density is ρ. Laplace's

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0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	4	8	9	10	10	10	10	8	5	3	1	1	0
0	8	20	20	20	20	20	20	20	9	5	2	1	0
0	9	20	20	20	20	20	20	20	9	4	2	1	0
0	10	20	20	18	16	14	12	9	5	2	0	0	0
0	10	20	20	16	12	9	5	1	−1	−2	−2	−1	0
0	10	20	20	14	9	3	−3	−7	−9	−8	−5	−3	0
0	10	20	20	12	5	−3	−11	−20	−20	−14	−9	−4	0
0	8	20	20	9	1	−7	−20	−20	−20	−20	−11	−5	0
0	5	9	9	5	−1	−9	−20	−20	−20	−20	−11	−5	0
0	3	5	4	2	−2	−8	−14	−20	−20	−14	−9	−4	0
0	1	2	2	0	−2	−5	−9	−11	−11	−9	−6	−3	0
0	1	1	1	0	−1	−3	−4	−5	−5	−4	−3	−2	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 10: Numerical solution for the electrode configuration shown in Figure 9. The electrostatic potentials are in volts (see text).

equation states that the divergence of the gradient of the potential is zero in regions of space with no charge. In the example of Figure 10, the potential on the conductors remains constant. Arbitrary values of potential are initially assigned elsewhere inside the cavity. To obtain a solution, a computer replaces the potential at each coordinate point that is not on a conductor by the average of the values of the potential around that point; it scans the entire set of points many times until the values of the potentials differ by an amount small enough to indicate a satisfactory solution. Clearly, the larger the number of points, the more accurate the solution will be. The computation time as well as the computer memory size requirement increase rapidly, however, especially in three-dimensional problems with complex geometry. This method of solution is called the "relaxation" method.

In Figure 11, points with the same value of electric potential have been connected to reveal a number of important properties associated with conductors in static situations. The lines in the figure represent equipotential surfaces. The distance between two equipotential surfaces tells how rapidly the potential changes, with the smallest distances corresponding to the location of the greatest rate of change and thus to the largest values of the electric field. Looking at the +20-volt and +15-volt equipotential surfaces, one observes immediately that they are closest to each other at the sharp external corners of the right-

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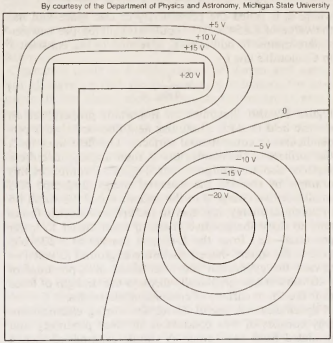

Figure 11: *Equipotential surfaces.*
The distance between two equipotential surfaces, represented by the lines, indicates how rapidly the potential changes. The smallest distances correspond to the location of the greatest rate of change and therefore to the largest values of the electric field.

angle conductor. This shows that the strongest electric fields on the surface of a charged conductor are found on the sharpest external parts of the conductor; electrical breakdowns are most likely to occur there. It also should be noted that the electric field is weakest in the inside corners, both on the inside corner of the right-angle piece and on the inside corners of the square enclosure.

In Figure 12, dashed lines indicate the direction of the electric field. The strength of the field is reflected by the density of these dashed lines. Again, it can be seen that the field is strongest on outside corners of the charged L-shaped conductor; the largest surface charge density must occur at those locations. The field is weakest in the inside corners. The signs of the charges on the conducting surfaces can be deduced from the fact that electric fields point away from positive charges and toward negative charges. The magnitude of the surface charge density σ on the conductors is measured in coulombs per metre squared and is given by

$$\sigma = \varepsilon_0 E_r \qquad (8)$$

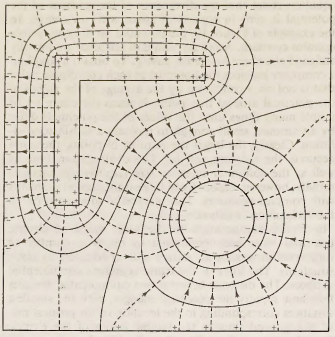

Figure 12: *Electric field lines.*
The density of the dashed lines indicates the strength of the field (see text).
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where ε_0 is called the permittivity of free space and has the value of 8.854×10^{-12} coulomb squared per newton-square metre. In addition, ε_0 is related to the constant k in Coulomb's law by

$$k = \frac{1}{4\pi\varepsilon_0}. \tag{9}$$

Field lines and equipotential surfaces

Figure 12 also illustrates an important property of an electric field in static situations: field lines are always perpendicular to equipotential surfaces. The field lines meet the surfaces of the conductors at right angles, since these surfaces also are equipotentials. Figure 13 completes this example by showing the potential energy landscape of a small positive charge q in the region. From the variation in potential energy, it is easy to picture how electric forces tend to drive the positive charge q from higher to lower potential—*i.e.*, from the L-shaped bracket at +20 volts toward the square-shaped enclosure at ground (0 volts) or toward the cylindrical rod maintained at a potential of −20 volts. It also graphically displays the strength of force near the sharp corners of conducting electrodes.

Capacitance. A useful device for storing electrical energy consists of two conductors in close proximity and insulated from each other. A simple example of such a storage device is the parallel-plate capacitor. If positive charges with total charge $+Q$ are deposited on one of the conductors and an equal amount of negative charge $-Q$ is deposited on the second conductor, the capacitor is said to have a charge Q. As shown in Figure 14, it consists of

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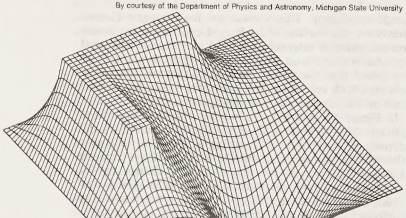

Figure 13: Potential energy for a positive charge (see text).

two flat conducting plates, each of area A, parallel to each other and separated by a distance d.

Principle of the capacitor

To understand how a charged capacitor stores energy, consider the following charging process. With both plates of the capacitor initially uncharged, a small amount of negative charge is removed from the lower plate and placed on the upper plate. Thus, little work is required to make the lower plate slightly positive and the upper plate slightly negative. As the process is repeated, however, it becomes increasingly difficult to transport the same amount of negative charge, since the charge is being moved toward a plate that is already negatively charged and away from a plate that is positively charged. The negative charge on the upper plate repels the negative charge moving toward it, and the positive charge on the lower plate exerts an attractive force on the negative charge being moved away. Therefore, work has to be done to charge the capacitor.

Where and how is this energy stored? The negative charges on the upper plate are attracted toward the positive charges on the lower plate and could do work if they could leave the plate. Because they cannot leave the plate, however, the energy is stored. A mechanical analogy is the potential energy of a stretched spring. Another way to understand the energy stored in a capacitor is to compare an uncharged capacitor with a charged capacitor. In the uncharged capacitor, there is no electric field between the plates; in the charged capacitor, because of the positive and negative charges on the inside surfaces of the plates, there is an electric field between the plates with the field lines pointing from the positively charged plate to the negatively charged one. The energy stored is the energy that

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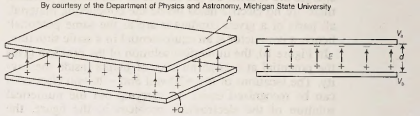

Figure 14: *Parallel-plate capacitor.*
(A) This storage device consists of two flat conducting plates, each of area A. (B) These plates are parallel and separated by a small distance d (see text).

was required to establish the field. In the simple geometry of Figure 14, it is apparent that there is a nearly uniform electric field between the plates; the field becomes more uniform as the distance between the plates decreases and the area of the plates increases. It was explained above how the magnitude of the electric field can be obtained from the electric potential. In summary, the electric field is the change in the potential across a small distance in a direction perpendicular to an equipotential surface divided by that small distance. In Figure 14, the upper plate is assumed to be at a potential of V_a volts, and the lower plate at a potential of V_b volts. The size of the electric field is

$$E = \frac{V_b - V_a}{d} \tag{10}$$

in volts per metre, where d is the separation of the plates. If the charged capacitor has a total charge of $+Q$ on the inside surface of the lower plate (it is on the inside surface because it is attracted to the negative charges on the upper plate), the positive charge will be uniformly distributed on the surface with the value

$$\sigma = \frac{Q}{A} \tag{11}$$

in coulombs per metre squared. Equation (8) gives the electric field when the surface charge density is known as $E = \sigma/\varepsilon_0$. This, in turn, relates the potential difference to the charge on the capacitor and the geometry of the plates. The result is

$$V_b - V_a = \frac{Qd}{\varepsilon_0 A} = \frac{Q}{C}. \tag{12}$$

The quantity C is termed capacity; for the parallel-plate capacitor, C is equal to $\varepsilon_0 A/d$. The unit used for capacity

is the farad (F); one farad equals one coulomb per volt. In equation (12), only the potential difference is involved. The potential of either plate can be set arbitrarily without altering the electric field between the plates. Often one of the plates is grounded—*i.e.*, its potential is set at the Earth potential, which is referred to as zero volts. The potential difference is then denoted as ΔV, or simply as V.

Three equivalent formulas for the total energy W of a capacitor with charge Q and potential difference V are

$$W = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}QV. \tag{13}$$

All are expressed in joules. The stored energy in the parallel-plate capacitor also can be expressed in terms of the electric field; it is, in joules,

$$W = \frac{1}{2}\varepsilon_0 E^2 (Ad). \tag{14}$$

The quantity Ad, the area of each plate times the separation of the two plates, is the volume between the plates. Thus, the energy per unit volume (*i.e.*, the energy density of the electric field) is given by $\frac{1}{2}\varepsilon_0 E^2$ in units of joules per metre cubed.

The amount of charge stored in a capacitor is the product of the voltage and the capacity. What limits the amount of charge that can be stored on a capacitor? The voltage can be increased, but electric breakdown will occur if the electric field inside the capacitor becomes too large. The capacity can be increased by expanding the electrode areas and by reducing the gap between the electrodes. In general, capacitors that can withstand high voltages have a relatively small capacity. If only low voltages are needed, however, compact capacitors with rather large capacities can be manufactured. One method for increasing capacity is to insert between the conductors an insulating material that reduces the voltage because of its effect on the electric field. Such materials are called dielectrics (substances with no free charges). When the molecules of a dielectric are placed in the electric field, their negatively charged electrons separate slightly from their positively charged cores. With this separation, referred to as polarization, the molecules acquire an electric dipole moment. A cluster of charges with an electric dipole moment is often called an electric dipole.

Polarization and electric dipole moment

Is there an electric force between a charged object and uncharged matter, such as a piece of wood? Surprisingly, the answer is yes, and the force is attractive. The reason is that under the influence of the electric field of a charged object, the negatively charged electrons and positively charged nuclei within the atoms and molecules are subjected to forces in opposite directions. As a result, the negative and positive charges separate slightly. Such atoms and molecules are said to be polarized and to have an electric dipole moment. The molecules in the wood acquire an electric dipole moment in the direction of the external electric field. The polarized molecules are attracted toward the charged object because the field increases in the direction of the charged object.

The electric dipole moment $\boldsymbol{p}$ of two charges $+q$ and $-q$ separated by a distance l is a vector of magnitude $p = ql$ with a direction from the negative to the positive charge. An electric dipole in an external electric field is subjected to a torque $\tau = pE \sin\theta$, where θ is the angle between $\boldsymbol{p}$ and $\boldsymbol{E}$. The torque tends to align the dipole moment $\boldsymbol{p}$ in the direction of $\boldsymbol{E}$. The potential energy of the dipole is given by $U_e = -pE\cos\theta$, or in vector notation $U_e = -\boldsymbol{p}\cdot\boldsymbol{E}$. In a nonuniform electric field, the potential energy of an electric dipole also varies with position, and the dipole can be subjected to a force. The force on the dipole is in the direction of increasing field when $\boldsymbol{p}$ is aligned with $\boldsymbol{E}$, since the potential energy U_e decreases in that direction.

The polarization of a medium $\boldsymbol{P}$ gives the electric dipole moment per unit volume of the material; it is expressed in units of coulombs per metre squared. When a dielectric is placed in an electric field, it acquires a polarization that depends on the field. The electric susceptibility χ_e relates the polarization to the electric field as $\boldsymbol{P} = \chi_e \boldsymbol{E}$. In general, χ_e varies slightly depending on the strength of the electric field, but for some materials, called linear dielectrics, it is a constant. The dielectric constant κ of a substance is related to its susceptibility as $\kappa = 1 + \chi_e/\varepsilon_0$; it is a dimensionless quantity. Table 1 lists the dielectric constants of a few substances.

Table 1: Dielectric Constants of Some Materials (at room temperature)

material	dielectric constant (κ)
Vacuum	1.0
Air	1.0006
Oil	2.2
Polyethylene	2.26
Beeswax	2.8
Fused quartz	3.78
Water	80
Calcium titanate	168
Barium titanate	1,250

The presence of a dielectric affects many electric quantities. A dielectric reduces by a factor K the value of the electric field and consequently also the value of the electric potential from a charge within the medium. As seen in Table 1, a dielectric can have a large effect. The insertion of a dielectric between the electrodes of a capacitor with a given charge reduces the potential difference between the electrodes and thus increases the capacitance of the capacitor by the factor K. For a parallel-plate capacitor filled with a dielectric, the capacity becomes $C = K\varepsilon_0 A/d$. A third and important effect of a dielectric is to reduce the speed of electromagnetic waves in a medium by the factor $\sqrt{K}$.

Effects of dielectrics

Capacitors come in a wide variety of shapes and sizes. Not all have parallel plates; some are cylinders, for example. If two plates, each one square centimetre in area, are separated by a dielectric with $K = 2$ of one millimetre thickness, the capacity is 1.76×10^{-12} F, about two picofarads. Charged to 20 volts, this capacitor would store about 40 picocoulombs of charge; the electric energy stored would be 400 picojoules. Even small-sized capacitors can store enormous amounts of charge. Modern techniques and dielectric materials permit the manufacture of capacitors that occupy less than one cubic centimetre and yet store 10^{10} times more charge and electric energy than in the above example.

Capacitors have many important applications. They are used, for example, in digital circuits so that information stored in large computer memories is not lost during a momentary electric power failure; the electric energy stored in such capacitors maintains the information during the temporary loss of power. Capacitors play an even more important role as filters to divert spurious electric signals and thereby prevent damage to sensitive components and circuits caused by electric surges. How capacitors provide such protection is discussed below in the section *Transient response*.

DIRECT ELECTRIC CURRENT

Basic phenomena and principles. Many electric phenomena occur under what is termed steady-state conditions. This means that such electric quantities as current, voltage, and charge distributions are not affected by the passage of time. For instance, because the current through a filament inside a car headlight does not change with time, the brightness of the headlight remains constant. An example of a nonsteady-state situation is the flow of charge between two conductors that are connected by a thin conducting wire and that initially have an equal but opposite charge. As current flows from the positively charged conductor to the negatively charged one, the charges on both conductors decrease with time, as does the potential difference between the conductors. The current therefore also decreases with time and eventually ceases when the conductors are discharged.

Steady-state phenomena

In an electric circuit under steady-state conditions, the flow of charge does not change with time and the charge distribution stays the same. Since charge flows from one location to another, there must be some mechanism to keep the charge distribution constant. In turn, the values

of the electric potentials remain unaltered with time. Any device capable of keeping the potentials of electrodes unchanged as charge flows from one electrode to another is called a source of electromotive force, or simply an emf.

Figure 15 shows a wire made of a conducting material such as copper. By some external means, an electric field is established inside the wire in a direction along its length.

By courtesy of the Department of Physics and Astronomy, Michigan State University

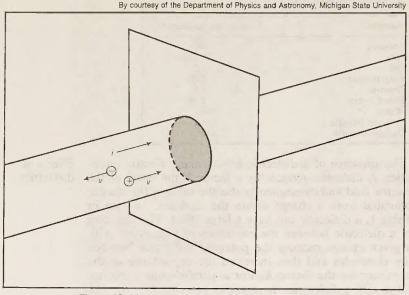

Figure 15: Motion of charge in electric current i (see text).

The electrons that are free to move will gain some speed. Since they have a negative charge, they move in the direction opposite that of the electric field. The current i is defined to have a positive value in the direction of flow of positive charges. If the moving charges that constitute the current i in a wire are electrons, the current is a positive number when it is in a direction opposite to the motion of the negatively charged electrons. (If the direction of motion of the electrons were also chosen to be the direction of a current, the current would have a negative value.) The current is the amount of charge crossing a plane transverse to the wire per unit time—*i.e.*, in a period of one second. If there are n free particles of charge q per unit volume with average velocity v and the cross-sectional area of the wire is A, the current i, in elementary calculus notation, is

$$i = \frac{dQ}{dt} = nevA, \tag{15}$$

where dQ is the amount of charge that crosses the plane in a time interval dt. The unit of current is the ampere (A); one ampere equals one coulomb per second. A useful quantity related to the flow of charge is current density, the flow of current per unit area. Symbolized by J, it has a magnitude of i/A and is measured in amperes per square metre.

Wires of different materials have different current densities for a given value of the electric field E; for many materials, the current density is directly proportional to the electric field. This behaviour is represented by Ohm's law:

$$J = \sigma_J E. \tag{16}$$

The proportionality constant σ_J is the conductivity of the material. In a metallic conductor, the charge carriers are electrons and, under the influence of an external electric field, they acquire some average drift velocity in the direction opposite the field. In conductors of this variety, the drift velocity is limited by collisions, which heat the conductor.

If the wire in Figure 15 has a length l and area A and if an electric potential difference of V is maintained between the ends of the wire, a current i will flow in the wire. The electric field E in the wire has a magnitude V/l. The equation for the current, using Ohm's law, is

$$i = JA = \frac{\sigma_J V}{l} A \tag{17}$$

or

$$V = i\frac{l}{\sigma_J A}. \tag{18}$$

The quantity $l/\sigma_J A$, which depends on both the shape and material of the wire, is called the resistance R of the wire. Resistance is measured in ohms (Ω). The equation for resistance,

$$R = \frac{l}{\sigma_J A}, \tag{19}$$

is often written as

$$R = \frac{\rho l}{A}, \tag{20}$$

where ρ is the resistivity of the material and is simply $1/\sigma_J$. The geometric aspects of resistance in equation (20) are easy to appreciate: the longer the wire, the greater the resistance to the flow of charge. A greater cross-sectional area results in a smaller resistance to the flow. Resistivity

The resistive strain gauge is an important application of equation (20). Strain, $\delta l/l$, is the fractional change in the length of a body under stress, where δl is the change of length and l is the length. The strain gauge consists of a thin wire or narrow strip of a metallic conductor such as constantan, an alloy of nickel and copper. A strain changes the resistance because the length, area, and resistivity of the conductor change. In constantan, the fractional change in resistance $\delta R/R$ is directly proportional to the strain with a proportionality constant of approximately 2.

A common form of Ohm's law is Ohm's law

$$V = iR, \tag{21}$$

where V is the potential difference in volts between the two ends of an element with an electric resistance of R ohms and where i is the current through that element.

Table 2 lists the resistivities of certain materials at room temperature. These values depend to some extent on temperature; therefore, in applications where the temperature is very different from room temperature, the proper values of resistivities must be used to calculate the resistance. As an example, equation (20) shows that a copper wire 59 metres long and with a cross-sectional area of one square millimetre has an electric resistance of one ohm at room temperature.

Table 2: Electric Resistivities (at room temperature)

material	resistivity ρ (ohm metre)
Silver	$1.6 \cdot 10^{-8}$
Copper	$1.7 \cdot 10^{-8}$
Aluminum	$2.7 \cdot 10^{-8}$
Carbon (graphite)	$1.4 \cdot 10^{-5}$
Germanium*	$4.7 \cdot 10^{-1}$
Silicon*	$2 \cdot 10^{3}$
Carbon (diamond)	$5 \cdot 10^{12}$
Polyethylene	$1 \cdot 10^{17}$
Fused quartz	$> 1 \cdot 10^{19}$

*Values very sensitive to purity.

Conductors, insulators, and semiconductors. Materials are classified as conductors, insulators, or semiconductors according to their electric conductivity. The classifications can be understood in atomic terms. Electrons in an atom can have only certain well-defined energies, and, depending on their energies, the electrons are said to occupy particular energy levels. In a typical atom with many electrons, the lower energy levels are filled, each with the number of electrons allowed by a quantum mechanical rule known as the Pauli exclusion principle. Depending on the element, the highest energy level to have electrons may or may not be completely full. If two atoms of some element are brought close enough together so that they interact, the two-atom system has two closely spaced levels for each level of the single atom. If 10 atoms interact, the 10-atom system will have a cluster of 10 levels corresponding to each single level of an individual atom. In a solid, the number of atoms and hence the number of levels is extremely large; most of the higher energy levels overlap in a continuous fashion except for certain energies in which there are no levels at all. Energy regions with levels are called energy bands, and regions that have no levels are referred to as band gaps. Energy bands and band gaps

The highest energy band occupied by electrons is the valence band. In a conductor, the valence band is partially filled, and since there are numerous empty levels, the electrons are free to move under the influence of an electric field; thus, in a metal the valence band is also the conduction band. In an insulator, electrons completely fill the valence band; and the gap between it and the next band, which is the conduction band, is large. The electrons cannot move under the influence of an electric field unless they are given enough energy to cross the large energy gap to the conduction band. In a semiconductor, the gap to the conduction band is smaller than in an insulator. At room temperature, the valence band is almost completely filled. A few electrons are missing from the valence band because they have acquired enough thermal energy to cross the band gap to the conduction band; as a result, they can move under the influence of an external electric field. The "holes" left behind in the valence band are mobile charge carriers but behave like positive charge carriers.

For many materials, including metals, resistance to the flow of charge tends to increase with temperature. For example, an increase of 5° C (9° F) increases the resistivity of copper by 2 percent. In contrast, the resistivity of insulators and especially of semiconductors such as silicon and germanium decreases rapidly with temperature; the increased thermal energy causes some of the electrons to populate levels in the conduction band where, influenced by an external electric field, they are free to move. The energy difference between the valence levels and the conduction band has a strong influence on the conductivity of these materials, with a smaller gap resulting in higher conduction at lower temperatures.

Range of resistivities in different materials

The values of electric resistivities listed in Table 2 show an extremely large variation in the capability of different materials to conduct electricity. The principal reason for the large variation is the wide range in the availability and mobility of charge carriers within the materials. The copper wire in Figure 15, for example, has many extremely mobile carriers; each copper atom has approximately one free electron, which is highly mobile because of its small mass. An electrolyte, such as a saltwater solution, is not as good a conductor as copper. The sodium and chlorine ions in the solution provide the charge carriers. The large mass of each sodium and chlorine ion increases as other attracted ions cluster around them. As a result, the sodium and chlorine ions are far more difficult to move than the free electrons in copper. Pure water also is a conductor, although it is a poor one because only a very small fraction of the water molecules are dissociated into ions. The oxygen, nitrogen, and argon gases that make up the atmosphere are somewhat conductive because a few charge carriers form when the gases are ionized by radiation from radioactive elements on the Earth as well as from extraterrestrial cosmic rays (*i.e.*, high-speed atomic nuclei and electrons). Electrophoresis is an interesting application based on the mobility of particles suspended in an electrolytic solution. Different particles (proteins, for example) move in the same electric field at different speeds; the difference in speed can be utilized to separate the contents of the suspension.

A current flowing through a wire heats it. This familiar phenomenon occurs in the heating coils of an electric range or in the hot tungsten filament of an electric light bulb. This ohmic heating is the basis for the fuses used to protect electric circuits and prevent fires; if the current exceeds a certain value, a fuse, which is made of an alloy with a low melting point, melts and interrupts the flow of current. The power P dissipated in a resistance R through which current i flows is given by

$$P = i^2R, \tag{22}$$

where P is in watts (one watt equals one joule per second), i is in amperes, and R is in ohms. According to Ohm's law, the potential difference V between the two ends of the resistor is given by $V = iR$, and so the power P can be expressed equivalently as

$$P = iV = \frac{V^2}{R}. \tag{23}$$

In certain materials, however, the power dissipation that manifests itself as heat suddenly disappears if the conductor is cooled to a very low temperature. The disappearance of all resistance is a phenomenon known as superconductivity. As mentioned earlier, electrons acquire some average drift velocity v under the influence of an electric field in a wire. Normally the electrons, subjected to a force because of an electric field, accelerate and progressively acquire greater speed. Their velocity is, however, limited in a wire because they lose some of their acquired energy to the wire in collisions with other electrons and in collisions with atoms in the wire. The lost energy is either transferred to other electrons, which later radiate, or the wire becomes excited with tiny mechanical vibrations referred to as phonons. Both processes heat the material. The term phonon emphasizes the relationship of these vibrations to another mechanical vibration—namely, sound. In a superconductor, a complex quantum mechanical effect prevents these small losses of energy to the medium. The effect involves interactions between electrons and also those between electrons and the rest of the material. It can be visualized by considering the coupling of the electrons in pairs with opposite momenta; the motion of the paired electrons is such that no energy is given up to the medium in inelastic collisions or phonon excitations. One can imagine that an electron about to "collide" with and lose energy to the medium could end up instead colliding with its partner so that they exchange momentum without imparting any to the medium.

Superconductivity

A superconducting material widely used in the construction of electromagnets is an alloy of niobium and titanium. This material must be cooled to a few degrees above absolute zero temperature, −263.66° C (or 9.5 K), in order to exhibit the superconducting property. Such cooling requires the use of liquefied helium, which is rather costly. During the late 1980s, materials that exhibit superconducting properties at much higher temperatures were discovered. These temperatures are higher than the −196° C of liquid nitrogen, making it possible to use the latter instead of liquid helium. Since liquid nitrogen is plentiful and cheap, such materials may provide great benefits in a wide variety of applications, ranging from electric power transmission to high-speed computing.

Sources of electromotive force

Electromotive force. A 12-volt automobile battery can deliver current to a circuit such as that of a car radio for a considerable length of time, during which the potential difference between the terminals of the battery remains close to 12 volts. The battery must have a means of continuously replenishing the excess positive and negative charges that are located on the respective terminals and that are responsible for the 12-volt potential difference between the terminals. The charges must be transported from one terminal to the other in a direction opposite to the electric force on the charges between the terminals. Any device that accomplishes this transport of charge constitutes a source of electromotive force. A car battery, for example, uses chemical reactions to generate electromotive force. The Van de Graaff generator shown in Figure 16 is a mechanical device that produces an electromotive force. Invented by the American physicist Robert J. Van de Graaff in the 1930s, this type of particle accelerator has been widely used to study subatomic particles. Because it is conceptually simpler than a chemical source of electromotive force, the Van de Graaff generator will be discussed first.

An insulating conveyor belt carries positive charge from the base of the Van de Graaff machine to the inside of a large conducting dome. The charge is removed from the belt by the proximity of sharp metal electrodes called charge remover points. The charge then moves rapidly to the outside of the conducting dome. The positively charged dome creates an electric field, which points away from the dome and provides a repelling action on additional positive charges transported on the belt toward the dome. Thus, work is done to keep the conveyor belt turning. If a current is allowed to flow from the dome to ground and if an equal current is provided by the transport of charge on the insulating belt, equilibrium is established and the potential of the dome remains at a constant positive value.

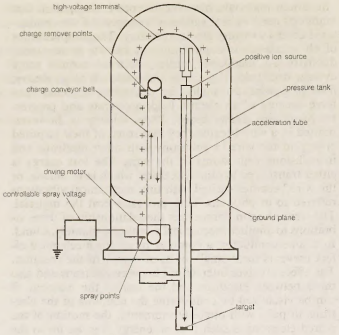

Figure 16: Van de Graaff accelerator.
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In this example, the current from the dome to ground consists of a stream of positive ions inside the accelerating tube, moving in the direction of the electric field. The motion of the charge on the belt is in a direction opposite to the force that the electric field of the dome exerts on the charge. This motion of charge in a direction opposite the electric field is a feature common to all sources of electromotive force.

In the case of a chemically generated electromotive force, chemical reactions release energy. If these reactions take place with chemicals in close proximity to each other (*e.g.*, if they mix), the energy released heats the mixture. To produce a voltaic cell, these reactions must occur in separate locations. A copper wire and a zinc wire poked into a lemon make up a simple voltaic cell. The potential difference between the copper and the zinc wires can be measured easily and is found to be 1.1 volts; the copper wire acts as the positive terminal. Such a "lemon battery" is a rather poor voltaic cell capable of supplying only small amounts of electric power. Another kind of 1.1-volt battery constructed with essentially the same materials can provide much more electricity. In this case, a copper wire is placed in a solution of copper sulfate and a zinc wire in a solution of zinc sulfate; the two solutions are connected electrically by a potassium chloride salt bridge. (A salt bridge is a conductor with ions as charge carriers.) In both kinds of batteries, the energy comes from the difference in the degree of binding between the electrons in copper and those in zinc. Energy is gained when copper ions from the copper sulfate solution are deposited on the copper electrode as neutral copper ions, thus removing free electrons from the copper wire. At the same time, zinc atoms from the zinc wire go into solution as positively charged zinc ions, leaving the zinc wire with excess free electrons. The result is a positively charged copper wire and a negatively charged zinc wire. The two reactions are separated physically, with the salt bridge completing the internal circuit.

Figure 17 illustrates a 12-volt lead-acid battery, using standard symbols for depicting batteries in a circuit. The battery consists of six voltaic cells, each with an electromotive force of approximately two volts; the cells are connected in series, so that the six individual voltages add up to about 12 volts (Figure 17A). As shown in Figure 17B, each two-volt cell consists of a number of positive and negative electrodes connected electrically in parallel. The parallel connection is made to provide a large surface area of electrodes, on which chemical reactions can take place. The higher rate at which the materials of the electrodes are able to undergo chemical transformations allows the battery to deliver a larger current.

In the lead-acid battery, each voltaic cell consists of a negative electrode of pure, spongy lead (Pb) and a positive electrode of lead oxide (PbO_2). Both the lead and lead oxide are in a solution of sulfuric acid (H_2SO_4) and water (H_2O). At the positive electrode, the chemical reaction is $PbO_2 + SO_4^- + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O + (1.68\ V)$. At the negative terminal, the reaction is $Pb + SO_4^- \rightarrow PbSO_4 + 2e^- + (0.36\ V)$. The cell potential is $1.68 + 0.36 = 2.04$ volts. The 1.68 and 0.36 volts in the above equations are, respectively, the reduction and oxidation potentials; they are related to the binding of the electrons in the chemicals. When the battery is recharged, either by a car generator or by an external power source, the two chemical reactions are reversed.

Direct-current circuits. The simplest direct-current (DC) circuit consists of a resistor connected across a source of electromotive force. The symbol for a resistor is shown in Figure 18; here the value of R, 60Ω, is given by the numerical value adjacent to the symbol. The symbol for a source of electromotive force, E, is shown with the associated value of the voltage. Convention gives the terminal with the long line a higher (*i.e.*, more positive) potential than the terminal with the short line. Straight lines connecting various elements in a circuit are assumed to have negligible resistance, so that there is no change in potential across these connections. The circuit shows a 12-volt electromotive force connected to a 60Ω resistor. The letters *a*, *b*, *c*, and *d* on the diagram are reference points.

Circuit elements

The function of the source of electromotive force is to maintain point *a* at a potential 12 volts more positive than point *d*. Thus, the potential difference $V_a - V_d$ is 12 volts. The potential difference across the resistance is $V_b - V_c$. From Ohm's law, the current i flowing through the resistor is

$$i = \frac{V_b - V_c}{R} = \frac{V_b - V_c}{60}. \qquad (24)$$

Since points *a* and *b* are connected by a conductor of negligible resistance, they are at the same potential. For the same reason, *c* and *d* are at the same potential. Therefore, $V_b - V_c = V_a - V_d = 12$ volts. The current in the circuit is given by equation (24). Thus, $i = 12/60 = 0.2$ ampere. The power dissipated in the resistor as heat is easily calculated using equation (22):

$$P = i^2R = (0.02)^2 \times 60 = 2.4 \text{ watts}.$$

Where does the energy that is dissipated as heat in the resistor come from? It is provided by a source of elec-

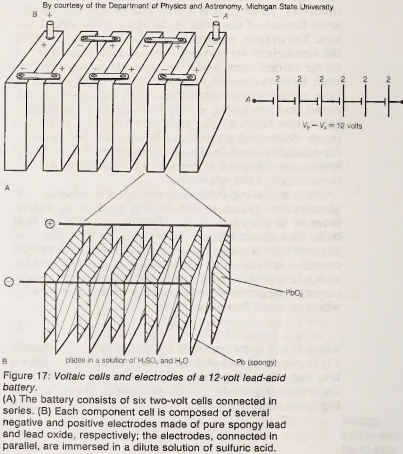

Figure 17: *Voltaic cells and electrodes of a 12-volt lead-acid battery.*
(A) The battery consists of six two-volt cells connected in series. (B) Each component cell is composed of several negative and positive electrodes made of pure spongy lead and lead oxide, respectively; the electrodes, connected in parallel, are immersed in a dilute solution of sulfuric acid.

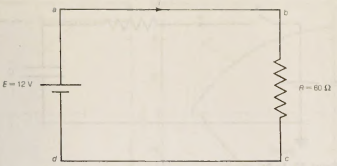

Figure 18: Direct-current circuit (see text).
By courtesy of the Department of Physics and Astronomy, Michigan State University

tromotive force (*e.g.*, a lead-acid battery). Within such a source, for each amount of charge dQ moved from the lower potential at d to the higher potential at a, an amount of work is done equal to $dW = dQ(V_a - V_d)$. If this work is done in a time interval dt, the power delivered by the battery is obtained by dividing dW by dt. Thus, the power delivered by the battery (in watts) is

$$\frac{dW}{dt} = (V_a - V_d)\frac{dQ}{dt} = (V_a - V_d)i.$$

Using the values $i = 0.2$ ampere and $V_a - V_d = 12$ volts makes $dW/dt = 2.4$ watts. As expected, the power delivered by the battery is equal to the power dissipated as heat in the resistor.

Resistors in series and parallel. If two resistors are connected in Figure 19A so that all of the electric charge must traverse both resistors in succession, the equivalent resistance to the flow of current is the sum of the resistances.

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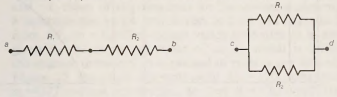

Figure 19: *Resistors.*
(A) In series. (B) In parallel.

Using R_1 and R_2 for the individual resistances, the resistance between a and b is given by

$$R_{ab} = R_1 + R_2. \tag{25a}$$

This result can be appreciated by thinking of the two resistors as two pieces of the same type of thin wire. Connecting the wires in series as shown simply increases their length to equal the sum of their two lengths. As equation (20) indicates, the resistance is the same as that given by equation (25a). The resistances R_1 and R_2 can be replaced in a circuit by the equivalent resistance R_{ab}. If $R_1 = 5\Omega$ and $R_2 = 2\Omega$, then $R_{ab} = 7\Omega$. If two resistors are connected as shown in Figure 19B, the electric charges have alternate paths for flowing from c to d. The resistance to the flow of charge from c to d is clearly less than if either R_1 or R_2 were missing. Anyone who has ever had to find a way out of a crowded theatre can appreciate how much easier it is to leave a building with several exits than one with a single exit. The value of the equivalent resistance for two resistors in parallel is given by the equation

$$\frac{1}{R_{cd}} = \frac{1}{R_1} + \frac{1}{R_2}. \tag{25b}$$

This relationship follows directly from the definition of resistance in equation (20), where $1/R$ is proportional to the area. If the resistors R_1 and R_2 are imagined to be wires of the same length and material, they would be wires with different cross-sectional areas. Connecting them in parallel is equivalent to placing them side by side, increasing the total area available for the flow of charge. Clearly, the equivalent resistance is smaller than the resistance of either resistor individually. As a numerical example, for $R_1 = 5\Omega$ and $R_2 = 2\Omega$, $1/R_{cd} = 1/5 + 1/2 = 0.7$. Therefore, $R_{cd} = 1/0.7 = 1.43\Omega$. As expected, the equivalent resistance of 1.43 ohms is smaller than either 2 ohms or 5 ohms. It should be noted that both equations (25a) and (25b) are given in a form in which they can be extended easily to any number of resistances.

Kirchhoff's laws of electric circuits. Two simple relationships can be used to determine the value of currents in circuits. They are useful even in rather complex situations such as circuits with multiple loops. The first relationship deals with currents at a junction of conductors. Figure 20 shows three such junctions, with the currents assumed to flow in the directions indicated.

Determining the value of currents in circuits

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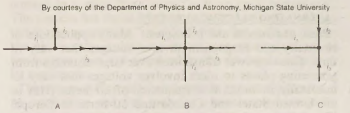

Figure 20: Electric currents at a junction (see text).

Simply stated, the sum of currents entering a junction equals the sum of currents leaving that junction. This statement is commonly called Kirchhoff's first law (after the German physicist Gustav Robert Kirchhoff, who formulated it). For Figure 20A, the sum is $i_1 + i_2 = i_3$. For Figure 20B, $i_1 = i_2 + i_3 + i_4$. For Figure 20C, $i_1 + i_2 + i_3 = 0$. If this last equation seems puzzling because all the currents appear to flow in and none flows out, it is because of the choice of directions for the individual currents. In solving a problem, the direction chosen for the currents is arbitrary. Once the problem has been solved, some currents have a positive value, and the direction arbitrarily chosen is the one of the actual current. In the solution some currents may have a negative value, in which case the actual current flows in a direction opposite that of the arbitrary initial choice.

Kirchhoff's second law is as follows: the sum of electromotive forces in a loop equals the sum of potential drops in the loop. When electromotive forces in a circuit are symbolized as circuit components as in Figure 18, this law can be stated quite simply: the sum of the potential differences across all the components in a closed loop equals zero. To illustrate and clarify this relation, one can consider a single circuit with two sources of electromotive forces E_1 and E_2, and two resistances R_1 and R_2, as shown in Figure 21. The direction chosen for the current i also is indicated. The letters a, b, c, and d are used to indicate certain locations around the circuit. Applying Kirchhoff's second law to the circuit,

$$(V_b - V_a) + (V_c - V_b) + (V_d - V_c) + (V_a - V_d) = 0. \tag{26}$$

Referring to the circuit in Figure 21, the potential differences maintained by the electromotive forces indicated are $V_b - V_a = E_1$, and $V_c - V_d = -E_2$. From Ohm's law, $V_b - V_c = iR_1$, and $V_d - V_a = iR_2$. Using these four relationships in equation (26), the so-called loop equation becomes $E_1 - E_2 - iR_1 - iR_2 = 0$.

By courtesy of the Department of Physics and Astronomy, Michigan State University

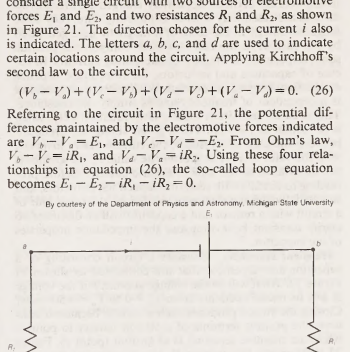

Figure 21: Circuit illustrating Kirchhoff's loop equation (see text).

Given the values of the resistances R_1 and R_2 in ohms and of the electromotive forces E_1 and E_2 in volts, the value of the current i in the circuit is obtained. If E_2 in the circuit had a greater value than E_1, the solution for the current i would be a negative value for i. This negative sign indicates that the current in the circuit would flow in a direction opposite the one indicated in Figure 21.

Kirchhoff's laws can be applied to circuits with several connected loops. The same rules apply, though the algebra required becomes rather tedious as the circuits increase in complexity.

ALTERNATING ELECTRIC CURRENTS

Use in power transmission and in radio and television broadcasting

Basic phenomena and principles. Many applications of electricity and magnetism involve voltages that vary in time. Electric power transmitted over large distances from generating plants to users involves voltages that vary sinusoidally in time, at a frequency of 60 hertz (Hz) in the United States and Canada and 50 hertz in Europe. (One hertz equals one cycle per second.) This means that in the United States, for example, the current alternates its direction in the electric conducting wires so that each second it flows 60 times in one direction and 60 times in the opposite direction. Alternating currents (AC) are also used in radio and television transmissions. In an AM (amplitude-modulation) radio broadcast, electromagnetic waves with a frequency of around one million hertz are generated by currents of the same frequency flowing back and forth in the antenna of the station. The information transported by these waves is encoded in the rapid variation of the wave amplitude. When voices and music are broadcast, these variations correspond to the mechanical oscillations of the sound and have frequencies from 50 to 5,000 hertz. In an FM (frequency-modulation) system, which is used by both television and FM radio stations, audio information is contained in the rapid fluctuation of the frequency in a narrow range around the frequency of the carrier wave.

Circuits that can generate such oscillating currents are called oscillators; they include, in addition to transistors and vacuum tubes, such basic electrical components as resistors, capacitors, and inductors. As was mentioned above, resistors dissipate heat while carrying a current. Capacitors store energy in the form of an electric field in the volume between oppositely charged electrodes. Inductors are essentially coils of conducting wire; they store magnetic energy in the form of a magnetic field generated by the current in the coil. All three components provide

Impedance

some impedance to the flow of alternating currents. In the case of capacitors and inductors, the impedance depends on the frequency of the current. With resistors, impedance is independent of frequency and is simply the resistance. This is easily seen from Ohm's law, equation (21), when it is written as $i = V/R$. For a given voltage difference V between the ends of a resistor, the current varies inversely with the value of R. The greater the value R, the greater is the impedance to the flow of electric current. Before proceeding to circuits with resistors, capacitors, inductors, and sinusoidally varying electromotive forces, the behaviour of a circuit with a resistor and a capacitor will be discussed to clarify transient behaviour and the impedance properties of the capacitor.

Transient response. Consider a circuit consisting of a capacitor and a resistor that are connected as shown in Figure 22. What will be the voltage at point b if the voltage at a is increased suddenly from $V_a = 0$ to $V_a = +50$ volts? Closing the switch produces such a voltage because it connects the positive terminal of a 50-volt battery to point a while the negative terminal is at ground (point c). Figure 23 (left) graphs this voltage V_a as a function of the time.

Initially, the capacitor has no charge and does not affect the flow of charge. The initial current is obtained from Ohm's law, $V = iR$, where $V = V_a - V_b$. V_a is 50 volts and V_b is zero. Using 2,000 ohms for the value of the resistance in Figure 22, there is an initial current of 25 milliamperes in the circuit. This current begins to charge the capacitor, so that a positive charge accumulates on the plate of the capacitor connected to point b and a negative charge accumulates on the other plate. As a result, the potential at

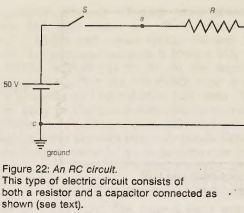

Figure 22: *An RC circuit.*
This type of electric circuit consists of both a resistor and a capacitor connected as shown (see text).
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point b increases from zero to a positive value. As more charge accumulates on the capacitor, this positive potential continues to increase. As it does so, the value of the potential across the resistor is reduced; consequently, the current decreases with time, approaching the value of zero as the capacitor potential reaches 50 volts. The behaviour of the potential at b in Figure 23 (right) is described by the equation $V_b = V_a(1 - e^{-t/RC})$ in volts. For $R = 2{,}000\,\Omega$ and capacitance $C = 2.5$ microfarads, $V_b = 50(1 - e^{-t/0.005})$ in volts. The potential V_b at b in Figure 23 (right) increases from zero when the capacitor is uncharged and reaches the ultimate value of V_a when equilibrium is reached.

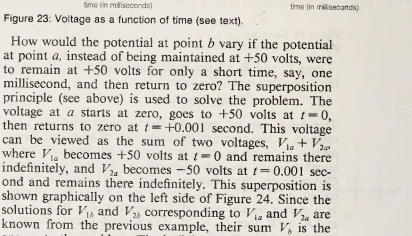

Figure 23: Voltage as a function of time (see text).

How would the potential at point b vary if the potential at point a, instead of being maintained at +50 volts, were to remain at +50 volts for only a short time, say, one millisecond, and then return to zero? The superposition principle (see above) is used to solve the problem. The voltage at a starts at zero, goes to +50 volts at $t = 0$, then returns to zero at $t = +0.001$ second. This voltage can be viewed as the sum of two voltages, $V_{1a} + V_{2a}$, where V_{1a} becomes +50 volts at $t = 0$ and remains there indefinitely, and V_{2a} becomes −50 volts at $t = 0.001$ second and remains there indefinitely. This superposition is shown graphically on the left side of Figure 24. Since the solutions for V_{1b} and V_{2b} corresponding to V_{1a} and V_{2a} are known from the previous example, their sum V_b is the answer to the problem. The individual solutions and their sum are given graphically on the right side of Figure 24.

The voltage at b reaches a maximum of only 9 volts. The superposition illustrated in Figure 24 also shows that the shorter the duration of the positive "pulse" at a, the smaller is the value of the voltage generated at b. Increasing the size of the capacitor also decreases the maximum voltage at b. This decrease in the potential of a transient explains the "guardian role" that capacitors play in protecting delicate and complex electronic circuits from damage by large transient voltages. These transients, which generally occur at high frequency, produce effects similar to those produced by pulses of short duration. They can damage equipment when they induce circuit components to break down electrically. Transient voltages are often introduced into electronic circuits through power supplies. A concise way to describe the role of the capacitor in the above example is to say that its impedance to an electric signal decreases with increasing frequency. In the example, much of the signal is shunted to ground instead of appearing at point b.

Transient voltages and their effects

Alternating-current circuits. Certain circuits include

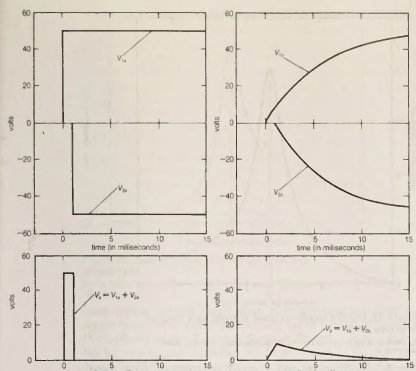

Figure 24: Application of the superposition principle to a problem concerned with voltages as a function of time (see text).

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sources of alternating electromotive forces of the sinusoidal form $V = V_0 \cos(\omega t)$ or $V = V_0 \sin(\omega t)$. The sine and cosine functions have values that vary between +1 and −1; either of the equations for the voltage represents a potential that varies with respect to time and has values from $+V_0$ to $-V_0$. The voltage varies with time at a rate given by the numerical value of ω; ω, which is called the angular frequency, is expressed in radians per second. Figure 25 shows an example with $V_0 = 170$ volts and $\omega = 377$ radians per second, so that $V = 170 \cos(377t)$. The time interval required for the pattern to be repeated is called the period T, given by $T = 2\pi/\omega$. In Figure 25, the pattern is repeated every 16.7 milliseconds, which is the period. The frequency of the voltage is symbolized by f and given by $f = 1/T$. In terms of ω, $f = \omega/2\pi$, in hertz.

The root-mean-square (rms) voltage of a sinusoidal source of electromotive force (V_{rms}) is used to characterize the source. It is the square root of the time average of the voltage squared. The value of V_{rms} is $V_0/\sqrt{2}$, or, equivalently, $0.707V_0$. Thus, the 60-hertz, 120-volt alternating current, which is available from most electric outlets in U.S. homes and which is illustrated in Figure 25, has $V_0 = 120/0.707 = 170$ volts. The potential difference at the outlet varies from +170 volts to −170 volts and back to +170 volts 60 times each second. The rms values of voltage and current are especially useful in calculating average power in AC circuits.

A sinusoidal electromotive force can be generated using

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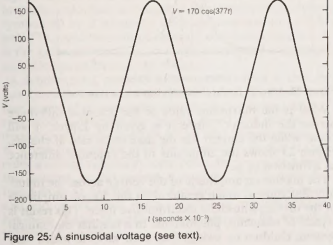

Figure 25: A sinusoidal voltage (see text).

the principles described in Faraday's law of electromagnetic induction (see below *Faraday's law of induction*). Briefly, an alternating electromotive force can be induced in a loop of conducting wire by rotating the loop of wire in a uniform magnetic field.

In AC circuits, it is often necessary to find the currents as a function of time in the various parts of the circuit for a given source of sinusoidal electromotive force. While the problems can become quite complex, the solutions are based on Kirchhoff's two laws discussed above (see *Kirchhoff's laws of electric circuits*). The solution for the current in a given loop takes the form $i = i_0 \cos(\omega t - \varphi)$. The current has the same frequency as the applied voltage but is not necessarily "in phase" with that voltage. When the phase angle φ does not equal zero, the maximum of the current does not occur when the driving voltage is at its maximum.

Behaviour of an AC circuit

The way an AC circuit functions can be better understood by examining one that includes a source of sinusoidally varying electromotive force, a resistor, a capacitor, and an inductor, all connected in series. For this single-loop problem, only the second of Kirchhoff's laws is needed since there is only one current. The circuit is shown in Figure 26 with the points *a*, *b*, *c*, and *d* at various positions in the circuit located between the various elements. The letters *R*, *L*, and *C* represent, respectively, the values of

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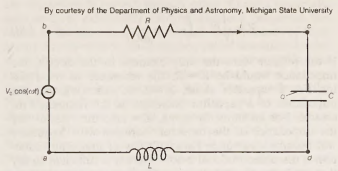

Figure 26: *A series LRC circuit.*
This type of electric circuit has an inductor, resistor, and capacitor connected in series (see text).

the resistance in ohms, the inductance in henrys, and the capacitance in farads. The source of the AC electromotive force is located between *a* and *b*. The wavy symbol is a reminder of the sinusoidal nature of the voltage that is responsible for making the current flow in the loop. For the potential between *b* and *a*,

$$V_b - V_a = V_0 \cos \omega t. \tag{27a}$$

Equation (27a) represents a potential difference that has its maximum positive value at $t = 0$.

The direction chosen for the current i in the circuit in Figure 26 represents the direction of that current at some particular time, since AC circuits feature continuous reversals of the direction of the flow of charge. The direction chosen for the current is important, however, because the loop equation must consider all the elements at the same instant in time. The potential difference across the resistor is given by Ohm's law as

$$V_b - V_c = iR. \tag{27b}$$

For equation (27b), the direction of the current is important. The potential difference across the capacitor, $V_c - V_d$, depends on the charge on the capacitor. When the charge on the upper plate of the capacitor in Figure 26 has a value Q, the potential difference across the capacitor is

$$V_c - V_d = \frac{Q}{C}, \tag{27c}$$

which is a variant of equation (12). One must be careful labeling the charge and the direction of the current, since the charge on the other plate is $-Q$. For the choices shown in the figure, the current in the circuit is given by the rate of change of the charge Q—that is, $i = dQ/dt$. Finally, the value of the potential difference $V_d - V_a$ across the inductor depends on the rate of change of the current through the inductor, di/dt. For the direction chosen for i, the value is

$$V_d - V_a = +L\frac{di}{dt}. \tag{27d}$$

The result of combining equations (27a, b, c, d) in accordance with Kirchhoff's second law for the loop in Figure 26 is

$$V_0 \cos(\omega t) = L\frac{di}{dt} + iR + \frac{Q}{C}. \tag{28}$$

Both the current i and the rate of change of the current di/dt can be eliminated from equation (28), since $i = dQ/dt$, and $di/dt = d^2Q/dt^2$. The result is a linear, inhomogeneous, second-order differential equation with well-known solutions for the charge Q as a function of time. The most important solution describes the current and voltages after transient effects have been dampened; the transient effects last only a short time after the circuit is completed. Once the charge is known, the current in the circuit can be obtained by taking the first derivative of the charge. The expression for the current in the circuit is

$$i = \frac{V_0}{Z}\cos(\omega t - \varphi) = i_0 \cos(\omega t - \varphi). \tag{29}$$

In equation (29), Z is the impedance of the circuit; impedance, like resistance, is measured in units of ohms. Z is a function of the frequency of the source of applied electromotive force. The equation for Z is

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}. \tag{30}$$

If the resistor were the only element in the circuit, the impedance would be $Z = R$, the resistance of the resistor. For a capacitor alone, $Z = 1/\omega C$, showing that the impedance of a capacitor decreases as the frequency increases. For an inductor alone, $Z = \omega L$; the reason why the impedance of the inductor increases with frequency will become clear once Faraday's law of magnetic induction is discussed in detail below. Here it is sufficient to say that an induced electromotive force in the inductor opposes the change in current, and it is directly proportional to the frequency.

The phase angle φ in equation (29) gives the time relationship between the current in the circuit and the driving electromotive force, $V_0 \cos(\omega t)$. The tangent of the angle φ is

$$\tan\varphi = \frac{\left(\omega L - \frac{1}{\omega C}\right)}{R}. \tag{31}$$

Depending on the values of ω, L, and C, the angle φ can be positive, negative, or zero. If φ is positive, the current "lags" the voltage, while for negative values of φ, the current "leads" the voltage.

The power dissipated in the circuit is the same as the power delivered by the source of electromotive force, and both are measured in watts. Using equation (23), the power is given by

$$P = iV = i_0 \cos(\omega t - \varphi) V_0 \cos(\omega t). \tag{32}$$

An expression for the average power dissipated in the circuit can be written either in terms of the peak values i_0 and V_0 or in terms of the rms values i_{rms} and V_{rms}. The average power is

$$P_{ave} = I_{rms} V_{rms} \cos\varphi = \frac{1}{2} i_0 V_0 \cos\varphi. \tag{33}$$

The cos φ in equation (33) is called the power factor. It is evident that the only element that can dissipate energy is the resistance.

Resonance

A most interesting condition known as resonance occurs when the phase angle is zero in equation (31), or equivalently, when the angular frequency ω has the value $\omega = \omega_r = \sqrt{1/LC}$. The impedance in equation (30) then has its minimum value and equals the resistance R. The amplitude of the current in the circuit, i_0, is at its maximum value (see equation [29]). Figure 27 shows the dependence of i_0 on the angular frequency ω of the source of alternating electromotive force. The values of the electric parameters for the figure are $V_0 = 50$ volts, $R = 25$ ohms,

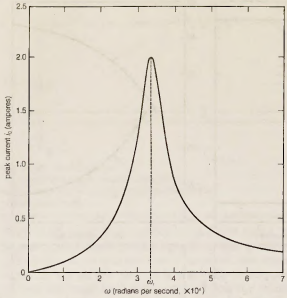

Figure 27: Current amplitude (peak current) as a function of ω (see text).

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$L = 4.5$ millihenrys, and $C = 0.2$ microfarad. With these values, the resonant angular frequency ω_r of the circuit in Figure 26 is 3.33×10^4 radians per second.

The peaking in the current shown in Figure 27 constitutes a resonance. At the resonant frequency, in this case when ω_r equals 3.33×10^4 radians per second, the impedance Z of the circuit is at a minimum and the power dissipated is at a maximum. The phase angle φ is zero so that the current is in phase with the driving voltage, and the power factor, cos φ, is 1. Figure 28 illustrates the variation of the average power with the angular frequency of the sinusoidal electromotive force. The resonance is seen to be even more pronounced. The quality factor Q for the circuit is the electric energy stored in the circuit divided by the energy dissipated in one period. The Q of a circuit is an important quantity in certain applications, as in the case of electromagnetic waveguides and radio-frequency cavities where Q has values around 10,000 and where high voltages and electric fields are desired. For the present circuit, $Q = \omega_r L/R$. Q also can be obtained from the average power graph as the ratio $\omega_r/(\omega_2 - \omega_1)$, where ω_1 and ω_2 are the angular frequencies at which the average power dissipated in the circuit is one-half its maximum value. For the circuit here, $Q = 6$.

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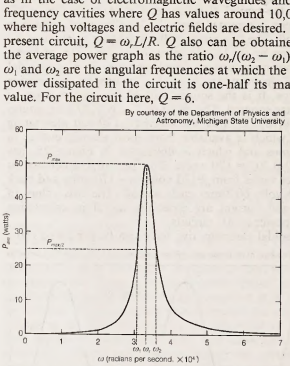

Figure 28: Average power dissipation versus ω (see text).

What is the maximum value of the potential difference across the inductor? Since it is given by Ldi/dt, it will occur when the current has the maximum rate of change. Figure 29 shows the amplitude of the potential difference as a function of ω.

The maximum amplitude of the voltage across the inductor, 300 volts, is much greater than the 50-volt amplitude of the driving sinusoidal electromotive force. This result is typical of resonance phenomena. In a familiar mechanical system, children on swings time their kicks to attain very

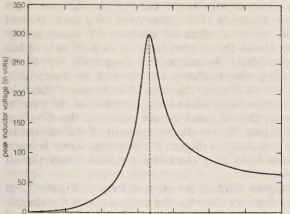

Figure 29: Electromotive force across L versus ω (see text).

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large swings (much larger than they could attain with a single kick). In a more spectacular, albeit costly, example, the collapse of the Tacoma Narrows Bridge (a suspension bridge across the Narrows of Puget Sound, Wash.) on Nov. 7, 1940, was the result of the large amplitudes of oscillations that the span attained as it was driven in resonance by high winds. A ubiquitous example of electric resonance occurs when a radio dial is turned to receive a broadcast. Turning the dial changes the value of the tuning capacitor of the radio. When the circuit attains a resonance frequency corresponding to the frequency of the radio wave, the voltage induced is enhanced and processed to produce sound.

Magnetism

FUNDAMENTALS

Magnetism is a phenomenon associated with the motion of charge. This motion can take many forms. It can be an electric current in a conductor or charged particles moving through space, or it can be the motion of an electron in atomic orbit. Magnetism is also associated with elementary particles, such as the electron, that have a property called spin.

Effects of a magnetic field

Basic to magnetism are magnetic fields and their effects on matter, as, for instance, the deflection of moving charges and torques on other magnetic objects. Evidence for the presence of a magnetic field is the magnetic force on charges moving in that field; the force is at right angles to both the field and the velocity of the charge. This force deflects the particles without changing their speed. The deflection can be observed in the electron beam of a television tube when a permanent magnet is brought near the tube. A more familiar example is the torque on a compass needle that acts to align the needle with the magnetic field of the Earth. The needle is a thin piece of iron that has been magnetized—*i.e.*, a small bar magnet. One end of the magnet is called a north pole and the other end a south pole. The force between a north and a south pole is attractive, whereas the force between like poles is repulsive. The magnetic field is sometimes referred to as magnetic induction or magnetic flux density; it is always symbolized by $\boldsymbol{B}$. Magnetic fields are measured in units of tesla (T). (Another unit of measure commonly used for $\boldsymbol{B}$ is the gauss, though it is no longer considered a standard unit. One gauss equals 10^{-4} tesla.)

A fundamental property of a magnetic field is that its flux through any closed surface vanishes. (A closed surface is one that completely surrounds a volume.) This is expressed mathematically by div $\boldsymbol{B} = 0$ and can be understood physically in terms of the field lines representing $\boldsymbol{B}$. These lines always close on themselves, so that if they enter a certain volume at some point, they must also leave that volume. In this respect, a magnetic field is quite different from an electric field. Electric field lines can begin and end on a charge, but no equivalent magnetic charge has been found in spite of many searches for so-called magnetic monopoles.

The most common source of magnetic fields is the electric current loop. It may be an electric current in a circular conductor or the motion of an orbiting electron in an atom. Associated with both these types of current loops is a magnetic dipole moment, the value of which is iA, the product of the current and the area of the loop. In addition, electrons, protons, and neutrons in atoms have a magnetic dipole moment associated with their intrinsic spin; such magnetic dipole moments represent another important source of magnetic fields. A particle with a magnetic dipole moment is often referred to as a magnetic dipole. (A magnetic dipole may be thought of as a tiny bar magnet. It has the same magnetic field as such a magnet and behaves the same way in external magnetic fields.) When placed in an external magnetic field, a magnetic dipole can be subjected to a torque that tends to align it with the field; if the external field is not uniform, the dipole also can be subjected to a force.

All matter exhibits magnetic properties to some degree. When placed in an inhomogeneous field, matter is either attracted or repelled in the direction of the gradient of the field. This property is described by the magnetic susceptibility of the matter and depends on the degree of magnetization of the matter in the field. Magnetization depends on the size of the dipole moments of the atoms in a substance and the degree to which the dipole moments are aligned with respect to each other. Certain materials, such as iron, exhibit very strong magnetic properties because of the alignment of the magnetic moments of their atoms within certain small regions called domains. Under normal conditions, the various domains have fields that cancel, but they can be aligned with each other to produce extremely large magnetic fields. Various alloys, like NdFeB (an alloy of neodymium, iron, and boron), keep their domains aligned and are used to make permanent magnets. The strong magnetic field produced by a typical three-millimetre-thick magnet of this material is comparable to an electromagnet made of a copper loop carrying a current of several thousand amperes. In comparison, the current in a typical light bulb is 0.5 ampere. Since aligning the domains of a material produces a magnet, disorganizing the orderly alignment destroys the magnetic properties of the material. Thermal agitation that results from heating a magnet to a high temperature destroys its magnetic properties.

Domains

Magnetic fields vary widely in strength. Some representative values are given in Table 3.

Table 3: Typical Magnetic Fields

Inside atomic nuclei	10^{11} T
In superconducting solenoids	20 T
In a superconducting coil cyclotron	5 T
Near a small ceramic magnet	0.1 T
Earth's field at the equator	4×10^{-5} T
In interstellar space	2×10^{-10} T

MAGNETIC FIELD OF STEADY CURRENTS

Biot–Savart law

Magnetic fields produced by electric currents can be calculated for any shape of circuit using the law of Biot and Savart, named for the early 19th-century French physicists Jean-Baptiste Biot and Félix Savart. A few magnetic field lines produced by a current in a loop are shown in Figure 30. These lines of $\boldsymbol{B}$ form loops around the current. The Biot–Savart law expresses the partial contribution $d\boldsymbol{B}$ from a small segment of conductor to the total $\boldsymbol{B}$ field of a current in the conductor. For a segment of length and orientation $d\boldsymbol{l}$ that carries a current i,

$$d\boldsymbol{B} = \frac{\mu_0}{4\pi} \frac{i d\boldsymbol{l} \times \hat{\boldsymbol{r}}}{r^2}. \tag{34}$$

In this equation, μ_0 is the permeability of free space and has the value of $4\pi \times 10^{-7}$ newton per square ampere. This equation is illustrated in Figure 31 for a small segment of a wire that carries a current so that, at the origin of the coordinate system, the small segment of length $d\boldsymbol{l}$ of the wire lies along the x axis.

Comparing $d\boldsymbol{B}$ at points 1 and 2 shows the inverse square dependence of the magnitude of the field with distance. The vectors at points 1, 3, and 4, which are all at the

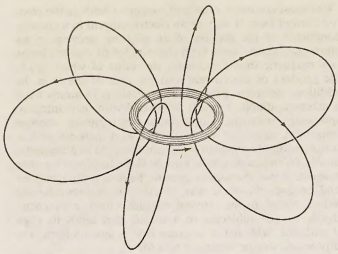

Figure 30: Some lines of the magnetic field $\boldsymbol{B}$ for an electric current i in a loop (see text).
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same distance from $d\boldsymbol{l}$, show the direction of $d\boldsymbol{B}$ in a circle around the wire. In position 1, the contribution to the field, $d\boldsymbol{B}_1$, is perpendicular both to the current direction and to the vector $\boldsymbol{r}_1$. Finally, the vectors at 1, 5, 6, and 7 illustrate the angular dependence of the magnitude of $d\boldsymbol{B}$ at a point. The magnitude of $d\boldsymbol{B}$ varies as the sine of the angle between $d\boldsymbol{l}$ and $\hat{\boldsymbol{r}}$, where $\hat{\boldsymbol{r}}$ is in the direction from $d\boldsymbol{l}$ to the point. It is strongest at 90° to $d\boldsymbol{l}$ and decreases to zero for locations directly in line with $d\boldsymbol{l}$. The magnetic field of a current in a loop or coil is obtained by summing the individual partial contributions of all the segments of the circuits, taking into account the vector nature of the field. While simple mathematical expressions for the magnetic field can be derived for a few current configurations, most of the practical applications require the use of high-speed computers.

The expression for the magnetic field $\boldsymbol{B}$ a distance r from a long straight wire with current i is

$$B = \frac{\mu_0 i}{2\pi r}\hat{\theta}, \tag{35}$$

where $\hat{\theta}$ is a unit vector pointing in a circle around the wire. The $\boldsymbol{B}$ field near a long straight wire with current i can be seen in Figures 2A and 2B. The magnetic field at a distance r from a magnetic dipole with moment $\boldsymbol{m}$ is given by

$$B = \frac{\mu_0 m}{4\pi r^3}(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta}). \tag{36}$$

The size of the magnetic dipole moment is m in ampere times square metre ($A \cdot m^2$), and the angle between the direction of $\boldsymbol{m}$ and of r is θ. Both $\hat{r}$ and $\hat{\theta}$ are unit vectors in the direction of $\boldsymbol{r}$ and θ. It is apparent that the magnetic field decreases rapidly as the cube of the distance from the dipole. Equation (36) is also valid for a small current loop with current i, when the distance r is much greater than the size of the current loop. A loop of area A has a magnetic dipole moment with a magnitude $m = iA$; its direction is perpendicular to the plane of the loop, along the direction of $\boldsymbol{B}$ inside the loop. If the fingers of the right hand are curled and held in the direction of the current in the loop, the extended thumb points in the direction of $\boldsymbol{m}$. In Figure 30, the dipole moment of the current in the loop points up; in Figure 32, $\boldsymbol{m}$ points down because the current flows in a clockwise direction when viewed from above.

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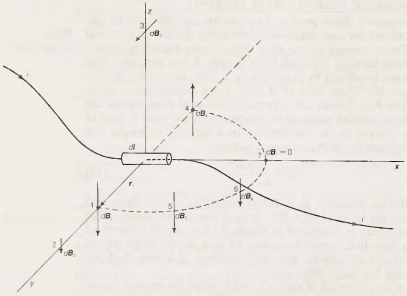

Figure 31: A magnetic field produced by a small section of wire with electric current i (see text).

The magnetic field of the current loop in Figure 32 at points far from the loop has the same shape as the electric field of an electric dipole; the latter consists of two equal charges of opposite sign separated by a small distance. Magnetic dipoles, like electric dipoles, occur in a variety of situations. Electrons in atoms have a magnetic dipole moment that corresponds to the current of their orbital motion around the nucleus. In addition, the electrons have a magnetic dipole moment associated with their spin. The Earth's magnetic field is thought to be the result of currents related to the planet's rotation. The magnetic field far from a small bar magnet is well represented by the field of a magnetic dipole. In most of these cases, moving charge produces a magnetic field $\boldsymbol{B}$. Inside a long solenoid with current i and away from its ends, the magnetic field is uniform and directed along the axis of the solenoid. A solenoid of this kind can be made by wrapping some conducting wire tightly around a long hollow cylinder. The value of the field is

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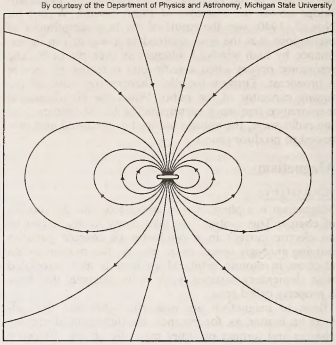

Figure 32: Some of the lines of $\boldsymbol{B}$ from the small current loop in the centre. The current in the loop flows in a clockwise direction when viewed from above.

$$B = \mu_0 ni, \tag{37}$$

where n is the number of turns per unit length of the solenoid.

MAGNETIC FORCES

A magnetic field $\boldsymbol{B}$ imparts a force on moving charged particles. The entire electromagnetic force on a charged particle with charge q and velocity $\boldsymbol{v}$ is called the Lorentz force (after the Dutch physicist Hendrik A. Lorentz) and is given by

Lorentz force

$$F = qE + qv \times B. \tag{38}$$

The first term is contributed by the electric field. The second term is the magnetic force and has a direction perpendicular to both the velocity $\boldsymbol{v}$ and the magnetic field $\boldsymbol{B}$. The magnetic force is proportional to q and to the magnitude of $v \times B$. In terms of the angle φ between $\boldsymbol{v}$ and $\boldsymbol{B}$, the magnitude of the force equals $qvB \sin \varphi$. An interest-

ing result of the Lorentz force is the motion of a charged particle in a uniform magnetic field. If v is perpendicular to B (*i.e.*, with the angle φ between v and B of 90°), the particle will follow a circular trajectory with a radius of $r = mv/qB$. If the angle φ is less than 90°, the particle orbit will be a helix with an axis parallel to the field lines. If φ is zero, there will be no magnetic force on the particle, which will continue to move undeflected along the field lines. Charged particle accelerators like cyclotrons make use of the fact that particles move in a circular orbit when v and B are at right angles. For each revolution, a carefully timed electric field gives the particles additional kinetic energy, which makes them travel in increasingly larger orbits. When the particles have acquired the desired energy, they are extracted and used in a number of different ways, from fundamental studies of the properties of matter to the medical treatment of cancer.

The magnetic force on a moving charge reveals the sign of the charge carriers in a conductor. A current flowing from right to left in a conductor can be the result of positive charge carriers moving from right to left or negative charges moving from left to right, or some combination of each. When a conductor is placed in a B field perpendicular to the current, the magnetic force on both types of charge carriers is in the same direction. This force, which can be seen in Figure 3, gives rise to a small potential difference between the sides of the conductor. Known as the Hall effect, this phenomenon (discovered by the American physicist Edwin H. Hall) results when an electric field is aligned with the direction of the magnetic force. As is evident in Figure 3, the sign of the potential differs according to the sign of the charge carrier because, in one case, positive charges are pushed toward the reader and, in the other, negative charges are pushed in that direction. The Hall effect shows that electrons dominate the conduction of electricity in copper. In zinc, however, conduction is dominated by the motion of positive charge carriers. Electrons in zinc that are excited from the valence band leave holes, which are vacancies (*i.e.*, unfilled levels) that behave like positive charge carriers. The motion of these holes accounts for most of the conduction of electricity in zinc.

Hall effect

If a wire with a current i is placed in an external magnetic field B, how will the force on the wire depend on the orientation of the wire? Since a current represents a movement of charges in the wire, the Lorentz force given in equation (38) acts on the moving charges. Because these charges are bound to the conductor, the magnetic forces on the moving charges are transferred to the wire. The force on a small length dl of the wire depends on the orientation of the wire with respect to the field. The magnitude of the force is given by $idlB \sin \varphi$, where φ is the angle between B and dl. There is no force when $\varphi = 0$ or 180°, both of which correspond to a current along a direction parallel to the field. The force is at a maximum when the current and field are perpendicular to each other. The force is obtained from equation (38) and is given by

$$dF = idl \times B. \tag{39}$$

Again, the cross product denotes a direction perpendicular to both dl and B. The direction of dF is given by the right-hand rule illustrated in Figure 33. As shown, the fingers are in the direction of B; the current (or in the case of a positive moving point charge, the velocity) is in the direction of the thumb, and the force is perpendicular to the palm.

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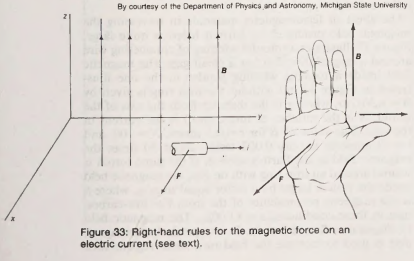

Figure 33: Right-hand rules for the magnetic force on an electric current (see text).

The force between two wires, each of which carries a current, can be understood from the interaction of one of the currents with the magnetic field produced by the other current. For example, the force between two parallel wires carrying currents in the same direction is attractive. It is repulsive if the currents are in opposite directions. Two circular current loops, located one above the other and with their planes parallel, will attract if the currents are in the same directions and will repel if the currents are in opposite directions. The situation is shown on the left side of Figure 34. When the loops are side by side as on the right side of Figure 34, the situation is reversed. For two currents flowing in the same direction, whether clockwise or counterclockwise, the force is repulsive, while for opposite directions, it is attractive. The nature of the force for the loops depicted in Figure 34 can be obtained by considering the direction of the currents in the parts of the loops that are closest to each other: same current direction, attraction; opposite current direction, repulsion. This seemingly complicated force between current loops can be understood more simply by treating the fields as though they originated from magnetic dipoles. As discussed above, the B field of a small current loop is well represented by the field of a magnetic dipole at distances that are large compared to the size of the loop. In another way of looking at the interaction of current loops, the loops of Figure 34A and 34B are replaced in Figure 35A and 35B by small permanent magnets, with the direction of the magnets from south to north corresponding to the direction of the magnetic moment of the loop m. Outside the magnets, the magnetic field lines point away from the north pole and toward the south pole.

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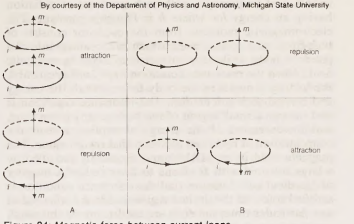

Figure 34: *Magnetic force between current loops.* In each case shown, the arrow indicates the direction of the current i and the magnetic dipole moment m of a loop (see text).

It is easy to understand the nature of the forces in Figures 34 and 35 with the rule that two north poles repulse each other and two south poles repulse each other, while unlike poles attract. As was noted earlier, Coulomb established an inverse square law of force for magnetic poles and electric charges; according to his law, unlike poles attract and like poles repel, just as unlike charges attract and like charges repel. Today, Coulomb's law refers only to charges, but historically it provided the foundation for a magnetic potential analogous to the electric potential.

The alignment of a magnetic compass needle with the direction of an external magnetic field is a good example of the torque to which a magnetic dipole is subjected. The torque has a magnitude $\tau = mB \sin \vartheta$. Here, ϑ is the angle between m and B. The torque τ tends to align m with B. It has its maximum value when ϑ is 90°, and it is zero when the dipole is in line with the external field. Rotating a magnetic dipole from a position where $\vartheta = 0$ to a position where $\vartheta = 180°$ requires work. Thus, the potential energy of the dipole depends on its orientation with respect to the field and is given in units of joules by

$$U_m = -mB \cos \vartheta. \tag{40}$$

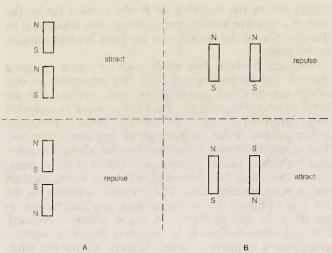

Figure 35: Force between small permanent bar magnets.
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Basis for magnetic resonance imaging

Equation (40) represents the basis for an important medical application—namely, magnetic resonance imaging (MRI), also known as nuclear magnetic resonance imaging. MRI involves measuring the concentration of certain atoms, most commonly those of hydrogen, in body tissue and processing this measurement data to produce high-resolution images of organs and other anatomical structures. When hydrogen atoms are placed in a magnetic field, their nuclei (protons) tend to have their magnetic moments preferentially aligned in the direction of the field. The magnetic potential energy of the nuclei is calculated according to equation (40) as $-mB$. Inverting the direction of the dipole moment requires an energy of $2mB$, since the potential energy in the new orientation is $+mB$. A high-frequency oscillator provides energy in the form of electromagnetic radiation of frequency ν, with each quantum of radiation having an energy $h\nu$, where h is Planck's constant. The electromagnetic radiation from the oscillator consists of high-frequency radio waves, which are beamed into the patient's body while it is subjected to a strong magnetic field. When the resonance condition $h\nu = 2mB$ is satisfied, the hydrogen nuclei in the body tissue absorb the energy and reverse their orientation. The resonance condition is met in only a small region of the body at any given time, and measurement of the energy absorption reveals the concentration of hydrogen atoms in that region alone. The magnetic field in an MRI scanner is usually provided by a large solenoid with B of one to three teslas. A number of "gradient coils" insures that the resonance condition is satisfied solely in the limited region inside the solenoid at any particular time; the coils are used to move this small target region, thereby making it possible to scan the patient's body throughout. The frequency of the radiation ν is determined by the value of B and is typically 40 to 130 megahertz. The MRI technique does not harm the patient because the energy of the quanta of the electromagnetic radiation is much smaller than the thermal energy of a molecule in the human body.

The direction of the magnetic moment $\boldsymbol{m}$ of a compass needle is from the end marked S for south to the one marked N for north. The lowest energy occurs for $\theta = 0$, when $\boldsymbol{m}$ and $\boldsymbol{B}$ are aligned. In a typical situation, the compass needle comes to rest after a few oscillations and points along the $\boldsymbol{B}$ field in the direction called north. It must be concluded from this that the Earth's North Pole is really a magnetic south pole, with the field lines pointing toward that pole, while its South Pole is a magnetic north pole. Put another way, the dipole moment of the Earth currently points north to south. Short-term changes in the Earth's magnetic field are ascribed to electric currents in the ionosphere. There are also longer-term fluctuations in the locations of the poles. The angle between the compass needle and geographic north is called the magnetic declination (see EARTH: *The magnetic field of the Earth*).

The repulsion or attraction between two magnetic dipoles can be viewed as the interaction of one dipole with the magnetic field produced by the other dipole. The magnetic field is not constant, but varies with the distance from the dipole. When a magnetic dipole with moment $\boldsymbol{m}$ is in a $\boldsymbol{B}$ field that varies with position, it is subjected to a force proportional to that variation—*i.e.*, to the gradient of $\boldsymbol{B}$. The direction of the force is understood best by considering the potential energy of a dipole in an external $\boldsymbol{B}$ field, as given by equation (40). The force on the dipole is in the direction in which that energy decreases most rapidly. For example, if the magnetic dipole $\boldsymbol{m}$ is aligned with $\boldsymbol{B}$, then the energy is $-mB$, and the force is in the direction of increasing $\boldsymbol{B}$. If $\boldsymbol{m}$ is directed opposite to $\boldsymbol{B}$, then the potential energy given by equation (40) is $+mB$, and in this case the force is in the direction of decreasing $\boldsymbol{B}$. Both types of forces are observed when various samples of matter are placed in a nonuniform magnetic field. Such a field from an electromagnet is sketched in Figure 36.

Regardless of the direction of the magnetic field in Figure 36, a sample of copper is magnetically attracted toward the low field region to the right in the drawing. This behaviour is termed diamagnetism. A sample of aluminum, however, is attracted toward the high field region in an effect called paramagnetism. A magnetic dipole moment is induced when matter is subjected to an external field.

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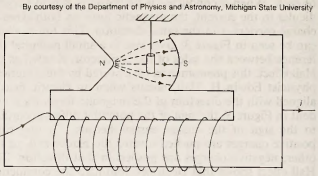

Figure 36: A small sample of copper in an inhomogeneous magnetic field (see text).

For copper, the induced dipole moment is opposite to the direction of the external field; for aluminum, it is aligned with that field. The magnetization $\boldsymbol{M}$ of a small volume of matter is the sum (a vector sum) of the magnetic dipole moments in the small volume divided by that volume. $\boldsymbol{M}$ is measured in units of amperes per metre. The degree of induced magnetization is given by the magnetic susceptibility of the material χ_m which is commonly defined by the equation

$$M = \chi_m H. \tag{41}$$

The field $\boldsymbol{H}$ is called the magnetic intensity and, like $\boldsymbol{M}$, is measured in units of amperes per metre. (It is sometimes also called the magnetic field, but the symbol $\boldsymbol{H}$ is unambiguous.) The definition of $\boldsymbol{H}$ is

$$H = \frac{B}{\mu_0} - M. \tag{42}$$

Magnetization effects in matter are discussed in some detail below. The permeability μ is often used for ferromagnetic materials such as iron that have a large magnetic susceptibility dependent on the field and the previous magnetic state of the sample; permeability is defined by the equation $B = \mu H$. From equations (41) and (42), it follows that $\mu = \mu_0 (1 + \chi_m)$.

The effect of ferromagnetic materials in increasing the magnetic field produced by current loops is quite large. Figure 37 illustrates a toroidal winding of conducting wire around a ring of iron that has a small gap. The magnetic field inside a toroidal winding similar to the one illustrated in Figure 37 but without the iron ring is given by $B = \mu_0 Ni/2\pi r$, where r is the distance from the axis of the toroid, N is the number of turns, and i is the current in the wire. The value of B for $r = 0.1$ metre, $N = 100$, and $i = 10$ amperes is only 0.002 tesla—about 50 times the magnetic field at the Earth's surface. If the same toroid is wound around an iron ring with no gap, the magnetic field inside the iron is larger by a factor equal to μ/μ_0, where μ is the magnetic permeability of the iron. For low-carbon iron in these conditions, $\mu = 8{,}000\mu_0$. The magnetic field in the iron is then 1.6 tesla. In a typical electromagnet, iron is used to increase the field in a small region, such

as the narrow gap in the iron ring illustrated in Figure 37. If the gap is one centimetre wide, the field in that gap is about 0.12 tesla, a 60-fold increase relative to the 0.002-tesla field in the toroid when no iron is used. This factor is typically given by the ratio of the circumference of the toroid to the gap in the ferromagnetic material. The maximum value of B as the gap becomes very small is of course the 1.6 tesla obtained above when there is no gap.

Energy density in a magnetic field

The energy density in a magnetic field is given in the absence of matter by $\frac{1}{2}B^2/\mu_0$; it is measured in units of joules per cubic metre. The total magnetic energy can be obtained by integrating the energy density over all space. The direction of the magnetic force can be deduced in many situations by studying distribution of the magnetic field lines; motion is favoured in the direction that tends to decrease the volume of space where the magnetic field is strong. This can be understood because the magnitude of $\boldsymbol{B}$ is squared in the energy density. Figure 38 shows some lines of the $\boldsymbol{B}$ field for two circular current loops with currents in opposite directions.

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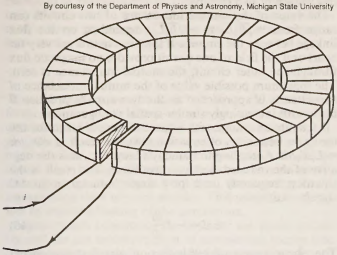

Figure 37: An electromagnet made of a toroidal winding around an iron ring that has a small gap (see text).

Because Figure 38 is a two-dimensional representation of a three-dimensional field, the spacing between the lines reflects the strength of the field only qualitatively. The high values of $\boldsymbol{B}$ between the two loops of the figure show that there is a large energy density in that region and separating the loops would reduce the energy. As discussed above, this is one more way of looking at the source of repulsion between these two loops. Figure 39 shows the $\boldsymbol{B}$ field for two loops with currents in the same direction. The force between the loops is attractive, and the distance separating them is equal to the loop radius. The result

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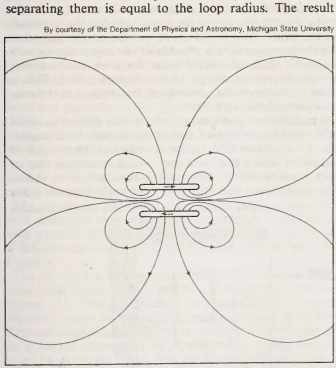

Figure 38: Magnetic field $\boldsymbol{B}$ of two current loops with currents in opposite directions (see text).

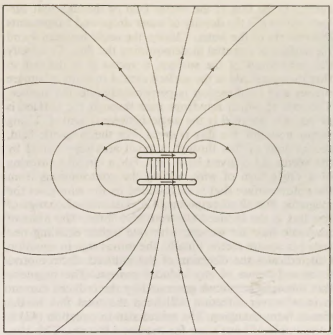

Figure 39: Magnetic field $\boldsymbol{B}$ of two current loops with currents in the same direction (see text).

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is that the $\boldsymbol{B}$ field in the central region between the two loops is homogeneous to a remarkably high degree. Such a configuration is called a Helmholtz coil. By carefully orienting and adjusting the current in a large Helmholtz coil, it is often possible to cancel an external magnetic field (such as the magnetic field of the Earth) in a region of space where experiments require the absence of all external magnetic fields.

Electromagnetism

The merger of electricity and magnetism from distinct phenomena into electromagnetism is tied to three closely related events. The first was Hans Christian Ørsted's accidental discovery of the influence of an electric current on a magnetic needle—namely, that magnetic fields are produced by electric currents. Ørsted's 1820 report of his observation spurred an intense effort by scientists to prove that magnetic fields can induce currents. The second event was Michael Faraday's experimental proof that a changing magnetic field can induce a current in a circuit. The third was James Clerk Maxwell's prediction that a changing electric field has an associated magnetic field. The technological revolution attributed to the development of electric power and radio communications can be traced to these three landmarks (see below).

EFFECTS OF VARYING MAGNETIC FIELDS

Faraday's law of induction. Faraday's discovery in 1831 of the phenomenon of magnetic induction is one of the great milestones in the quest toward understanding and exploiting nature. Stated simply, Faraday found that (1) a changing magnetic field in a circuit induces an electromotive force in the circuit; and (2) the magnitude of the electromotive force equals the rate at which the flux of the magnetic field through the circuit changes. The flux is a measure of how much field penetrates through the circuit. The electromotive force is measured in volts and is represented by the equation

Magnetic flux

$$\text{emf} = -\frac{d\Phi}{dt}. \tag{43}$$

Here, Φ, the flux of the vector field $\boldsymbol{B}$ through the circuit, measures how much of the field passes through the circuit. To illustrate the meaning of flux, imagine how much water from a steady rain will pass through a circular ring of area A. When the ring is placed parallel to the path of the water drops, no water passes through the ring. The maximum rate at which drops of rain pass through the ring occurs when the surface is perpendicular to the motion of the drops. The rate of water drops crossing the

surface is the flux of the vector field ρv through that surface, where ρ is the density of water drops and v represents the velocity of the water. Clearly, the angle between v and the surface is essential in determining the flux. To specify the orientation of the surface, a vector A is defined so that its magnitude is the surface area A in units of square metres and its direction is perpendicular to the surface. The rate at which raindrops pass through the surface is $\rho v \cos \theta A$, where θ is the angle between v and A. Using vector notation, the flux is $\rho v \cdot A$. For the magnetic field, the amount of flux through a small area represented by the vector dA is given by $B \cdot dA$. For a circuit consisting of a single turn of wire, adding the contributions from the entire surface that is surrounded by the wire gives the magnetic flux Φ of equation (43). The rate of change of this flux is the induced electromotive force. The units of magnetic flux are webers, with one weber equaling one tesla per square metre. Finally, the minus sign in equation (43) indicates the direction of the induced electromotive force and hence of any induced current. The magnetic flux through the circuit generated by the induced current is in whatever direction will keep the total flux in the circuit from changing. The minus sign in equation (43) is an example of Lenz's law for magnetic systems. This law, deduced by the Russian-born physicist Heinrich Friedrich Emil Lenz, states that "what happens is that which opposes any change in the system."

Faraday's law is valid regardless of the process that causes the magnetic flux to change. It may be that a magnet is moved closer to a circuit or that a circuit is moved closer to a magnet. Figure 40 shows a magnet brought near a conducting ring and gives the direction of the induced current and field, thus illustrating both Faraday's and Lenz's laws. Another alternative is that the circuit may change in size in a fixed external magnetic field or, as in the case of alternating-current generation, that the circuit may be a coil of conducting wire rotating in a magnetic field so that the flux Φ varies sinusoidally in time.

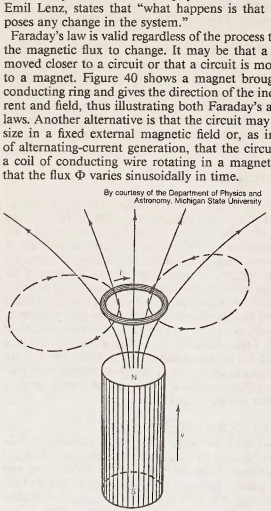

Figure 40: *Demonstration of Faraday's and Lenz's laws.* When a magnet is moved toward a conducting ring, an induced electromotive force causes a current i to flow in a direction such that the magnetic field inside the ring (represented by the two dashed field lines) opposes the increase of flux through the ring from the approaching magnet (see text).

The magnetic flux Φ through a circuit has to be considered carefully in the application of Faraday's law given in equation (43). For example, if a circuit consists of a coil with five closely spaced turns and if φ is the magnetic flux through a single turn, then the value of Φ for the five-turn circuit that must be used in Faraday's law is $\Phi = 5\varphi$. If the five turns are not the same size and closely spaced, the problem of determining Φ can be quite complex.

Self-inductance and mutual inductance. The self-inductance of a circuit is used to describe the reaction of the circuit to a changing current in the circuit, while the mutual inductance with respect to a second circuit describes the reaction to a changing current in the second circuit. When a current i_1 flows in circuit 1, i_1 produces a magnetic field B_1; the magnetic flux through circuit 1 due to current i_1 is Φ_{11}. Since B_1 is proportional to i_1, Φ_{11} is as well. The constant of proportionality is the self-inductance L_1 of the circuit. It is defined by the equation

$$\Phi_{11} = L_1 i_1. \tag{44}$$

As indicated earlier, the units of inductance are henrys. If a second circuit is present, some of the field B_1 will pass through circuit 2 and there will be a magnetic flux Φ_{21} in circuit 2 due to the current i_1. The mutual inductance M_{21} is given by

$$\Phi_{21} = M_{21} i_1. \tag{45}$$

The magnetic flux in circuit 1 due to a current in circuit 2 is given by $\Phi_{12} = M_{12} i_2$. An important property of the mutual inductance is that $M_{21} = M_{12}$. It is therefore sufficient to use the label M without subscripts for the mutual inductance of two circuits.

The value of the mutual inductance of two circuits can range from $+\sqrt{L_1 L_2}$ to $-\sqrt{L_1 L_2}$, depending on the flux linkage between the circuits. If the two circuits are very far apart or if the field of one circuit provides no magnetic flux through the other circuit, the mutual inductance is zero. The maximum possible value of the mutual inductance of two circuits is approached as the two circuits produce B fields with increasingly similar spatial configurations.

If the rate of change with respect to time is taken for the terms on both sides of equation (44), the result is $d\Phi_{11}/dt = L_1 di_1/dt$. According to Faraday's law, $d\Phi_{11}/dt$ is the negative of the induced electromotive force. The result is the equation frequently used for a single inductor in an AC circuit—*i.e.*,

$$\text{emf} = -L\frac{di}{dt}. \tag{46}$$

The phenomenon of self-induction was first recognized by the American scientist Joseph Henry. He was able to generate large and spectacular electric arcs by interrupting the current in a large copper coil with many turns. While a steady current is flowing in a coil, the energy in the magnetic field is given by $\frac{1}{2}Li^2$. If both the inductance L and the current i are large, the amount of energy is also large. If the current is interrupted, as, for example, by opening a knife-blade switch, the current and therefore the magnetic flux through the coil drop quickly. Equation (46) describes the resulting electromotive force induced in the coil, and a large potential difference is developed between the two poles of the switch. The energy stored in the magnetic field of the coil is dissipated as heat and radiation in an electric arc across the space between the terminals of the switch. Due to advances in superconducting wires for electromagnets, it is possible to use large magnets with magnetic fields of several teslas for temporarily storing electric energy as energy in the magnetic field. This is done to accommodate short-term fluctuations in the consumption of electric power.

A transformer is an example of a device that uses circuits with maximum mutual induction. Figure 41 illustrates the configuration of a typical transformer. Here, coils of insulated conducting wire are wound around a ring of iron constructed of thin isolated laminations or sheets. The laminations minimize eddy currents in the iron. Eddy

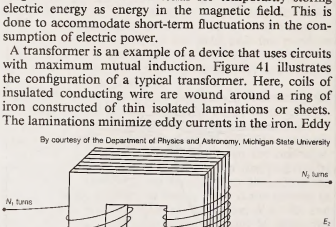

Figure 41: An AC transformer (see text).

Eddy currents

currents are circulatory currents induced in the metal by the changing magnetic field. These currents produce an undesirable by-product—heat in the iron. Energy loss in a transformer can be reduced by using thinner laminations, very "soft" (low-carbon) iron and wire with a larger cross section, or by winding the primary and secondary circuits with conductors that have very low resistance. Unfortunately, reducing the heat loss increases the cost of transformers. Transformers used to transmit and distribute power are commonly 98 to 99 percent efficient. While eddy currents are a problem in transformers, they are useful for heating objects in a vacuum. Eddy currents are induced in the object to be heated by surrounding a relatively nonconducting vacuum enclosure with a coil carrying a high-frequency alternating current.

In a transformer, the iron ensures that nearly all the lines of $\boldsymbol{B}$ passing through one circuit also pass through the second circuit and that, in fact, essentially all the magnetic flux is confined to the iron. Each turn of the conducting coils has the same magnetic flux; thus, the total flux for each coil is proportional to the number of turns in the coil. As a result, if a source of sinusoidally varying electromotive force is connected to one coil, the electromotive force in the second coil is given by

$$\text{emf}_2 = \text{emf}_1 \frac{N_2}{N_1}. \tag{47}$$

Thus, depending on the ratio of N_2 to N_1, the transformer can be either a step-up or a step-down device for alternating voltages. For many reasons, including safety, generation and consumption of electric power occur at relatively low voltages. Step-up transformers are used to obtain high voltages before electric power is transmitted, since for a given amount of power, the current in the transmission lines is much smaller. This minimizes energy lost by resistive heating of the conductors.

Faraday's law constitutes the basis for the power industry and for the transformation of mechanical energy into electric energy. In 1821, a decade before his discovery of magnetic induction, Faraday conducted experiments with electric wires rotating around compass needles. This earlier work, in which a wire carrying a current rotated around a magnetized needle and a magnetic needle was made to rotate around a wire carrying an electric current, provided the groundwork for the development of the electric motor.

EFFECTS OF VARYING ELECTRIC FIELDS

Maxwell's prediction that a changing electric field generates a magnetic field was a masterstroke of pure theory. The Maxwell equations for the electromagnetic field unified all that was hitherto known about electricity and magnetism and predicted the existence of an electromagnetic phenomenon that can travel as waves with the velocity of $1/\sqrt{\varepsilon_0\mu_0}$ in a vacuum. That velocity, which is based on constants obtained from purely electric measurements, corresponds to the speed of light. Consequently, Maxwell concluded that light itself was an electromagnetic phenomenon. Later, Einstein's special relativity theory postulated that the value of the speed of light is independent of the motion of the source of the light. Since then, the speed of light has been measured with increasing accuracy. In 1983 it was defined to be exactly 299,792,458 metres per second. Together with the cesium clock, which has been used to define the second, the speed of light serves as the new standard for length.

The circuit in Figure 42 is an example of a magnetic field generated by a changing electric field. A capacitor with parallel plates is charged at a constant rate by a steady current flowing through the long, straight leads in Figure 42A.

Ampère's law in circuital form

The objective is to apply Ampère's circuital law for magnetic fields to the path P, which goes around the wire in Figure 42A. This law (named in honour of the French physicist André-Marie Ampère) can be derived from the Biot and Savart equation for the magnetic field produced by a current (equation [34]). Using vector calculus notation, Ampère's law states that the integral $\oint \boldsymbol{B} \cdot d\boldsymbol{l}$ along a closed path surrounding the current i is equal to $\mu_0 i$. (An integral is essentially a sum, and, in this case, $\oint \boldsymbol{B} \cdot d\boldsymbol{l}$ is

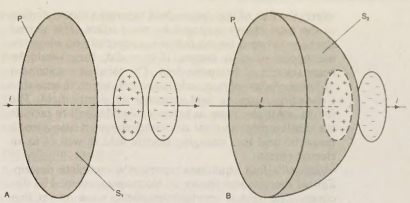

Figure 42: Current i charging a capacitor as an illustration of Maxwell's displacement current (see text).
By courtesy of the Department of Physics and Astronomy, Michigan State University

the sum of $B \cos \theta dl$ taken for a small length of the path until the complete loop is included. At each segment of the path dl, θ is the angle between the field $\boldsymbol{B}$ and $d\boldsymbol{l}$.) The current i in Ampère's law is the total flux of the current density $\boldsymbol{J}$ through any surface surrounded by the closed path. In Figure 42A, the closed path is labeled P, and a surface S_1 is surrounded by path P. All the current density through S_1 lies within the conducting wire. The total flux of the current density is the current i flowing through the wire. The result for surface S_1 reflects the value of the magnetic field around the wire in the region of the path P. In Figure 42B, path P is the same but the surface S_2 passes between the two plates of the capacitor. The value of the total flux of the current density through the surface should also be i. There is, however, clearly no motion of charge at all through the surface S_2. The dilemma is that the value of the integral $\oint \boldsymbol{B} \cdot d\boldsymbol{l}$ for the path P cannot be both $\mu_0 i$ and zero.

Maxwell's resolution of this dilemma was his conclusion that there must be some other kind of current density, called the displacement current $\boldsymbol{J}_d$, for which the total flux through the surface S_2 would be the same as the current i through the surface S_1. $\boldsymbol{J}_d$ would take, for the surface S_2, the place of the current density $\boldsymbol{J}$ associated with the movement of charge, since $\boldsymbol{J}$ is clearly zero due to the lack of charges between the plates of the capacitor. What happens between the plates while the current i is flowing? Because the amount of charge on the capacitor increases with time, the electric field between the plates increases with time too. If the current stops, there is an electric field between the plates as long as the plates are charged, but there is no magnetic field around the wire. Maxwell decided that the new type of current density was associated with the changing of the electric field. He found that

$$\boldsymbol{J}_d = \frac{d\boldsymbol{D}}{dt}, \tag{48}$$

where $\boldsymbol{D} = \varepsilon_0 \boldsymbol{E}$ and $\boldsymbol{E}$ is the electric field between the plates. In situations where matter is present, the field $\boldsymbol{D}$ in equation (48) is modified to include polarization effects; the result is $\boldsymbol{D} = \varepsilon_0 \boldsymbol{E} + \boldsymbol{P}$. The field $\boldsymbol{D}$ is measured in coulombs per square metre. Adding the displacement current to Ampère's law represented Maxwell's prediction that a changing electric field also could be a source of the magnetic field $\boldsymbol{B}$. Following Maxwell's predictions of electromagnetic waves, the German physicist Heinrich Hertz initiated the era of radio communications in 1887 by generating and detecting electromagnetic waves.

Maxwell's equations

Using vector calculus notation, the four equations of Maxwell's theory of electromagnetism are

$$\text{I. } \operatorname{div} \boldsymbol{D} = \rho, \tag{49}$$

$$\text{II. } \operatorname{div} \boldsymbol{B} = 0, \tag{50}$$

$$\text{III. } \textit{curl}\ \boldsymbol{E} = -\frac{d\boldsymbol{B}}{dt}, \tag{51}$$

$$\text{IV. } \textit{curl}\ \boldsymbol{H} = \boldsymbol{J} + \frac{d\boldsymbol{D}}{dt}, \tag{52}$$

where $\boldsymbol{D} = \varepsilon_0 \boldsymbol{E} + \boldsymbol{P}$, and $\boldsymbol{H} = \boldsymbol{B}/\mu_0 - \boldsymbol{M}$. The first equation is based on Coulomb's inverse square law for the force between two charges; it is a form of Gauss's law, which

relates the flux of the electric field through a closed surface to the total charge enclosed by the surface. The second equation is based on the fact that apparently no magnetic monopoles exist in nature; if they did, they would be point sources of magnetic field. The third is a statement of Faraday's law of magnetic induction, which reveals that a changing magnetic field generates an electric field. The fourth is Ampère's law as extended by Maxwell to include the displacement current discussed above; it associates a magnetic field to a changing electric field as well as to an electric current.

Maxwell's four equations represent a complete description of the classical theory of electromagnetism. His discovery that light is an electromagnetic wave meant that optics could be understood as part of electromagnetism. Only in microscopic situations is it necessary to modify Maxwell's equations to include quantum effects. That modification, known as quantum electrodynamics (QED), accounts for certain atomic properties to a degree of precision exceeding one part in 100 million.

Sometimes it is necessary to shield apparatus from external electromagnetic fields. For a static electric field, this is a simple matter; the apparatus is surrounded by a shield made of a good conductor (*e.g.*, copper). Shielding apparatus from a steady magnetic field is more difficult because materials with infinite magnetic permeability μ do not exist; for example, a hollow shield made of soft iron will reduce the magnetic field inside to a considerable extent but not completely. As discussed earlier, it is sometimes possible to superpose a field in the opposite direction to produce a very low field region and then to use additional material with a high μ for shielding. In the case of electromagnetic waves, the penetration of the waves in matter varies, depending on the frequency of the radiation and the electric conductivity of the medium. The skin depth δ (which is the distance in the conducting medium traversed for an amplitude decrease of $1/e$, about 1/3) is given by

$$\delta = \sqrt{\frac{2}{\omega\mu_0\sigma_f}}.$$

At high frequency, the skin depth is small. Therefore, to transmit electronic messages through seawater, for example, a very low frequency must be used to get a reasonable fraction of the signal far below the surface.

A metal shield can have some holes in it and still be effective. For instance, a typical microwave oven has a frequency of 2.5 gigahertz, which corresponds to a wavelength of about 12 centimetres for the electromagnetic wave inside the oven. The metal shield on the door has small holes about two millimetres in diameter; the shield works because the wavelength of the microwave radiation is much greater than the size of the holes. On the other hand, the same shield is not effective with radiation of a much shorter wavelength. Visible light passes through the holes in the shield, as evidenced by the fact that it is possible to see inside a microwave oven when the door is closed.

(E.Ka./S.McG.)

Electric properties of matter

PIEZOELECTRICITY

Electric polarization due to mechanical stress

Some solids, notably certain crystals, have permanent electric polarization. Other crystals become electrically polarized when subjected to stress. In electric polarization, the centre of positive charge within an atom, molecule, or crystal lattice element is separated slightly from the centre of negative charge. Piezoelectricity (literally "pressure electricity") is observed if a stress is applied to a solid, for example, by bending, twisting, or squeezing it. If a thin slice of quartz is compressed between two electrodes, a potential difference occurs; conversely, if the quartz crystal is inserted into an electric field, the resulting stress changes its dimensions. Piezoelectricity is responsible for the great precision of clocks and watches equipped with quartz oscillators. It also is used in electric guitars and various other musical instruments to transform mechanical vibrations into corresponding electric signals, which are then amplified and converted to sound by acoustical speakers.

A crystal under stress exhibits the direct piezoelectric effect; a polarization P, proportional to the stress, is produced. In the converse effect, an applied electric field produces a distortion of the crystal, represented by a strain proportional to the applied field. The basic equations of piezoelectricity are $P = d \times stress$ and $E = strain/d$. The piezoelectric coefficient d (in metres per volt) is approximately 3×10^{-12} for quartz, 5×-10^{-11} for ammonium dihydrogen phosphate, and 3×10^{-10} for lead zirconate titanate.

For an elastic body, the stress is proportional to the strain—*i.e.*, $stress = Y_e \times strain$. The proportionality constant is the coefficient of elasticity Y_e, also called Young's modulus for the English physicist Thomas Young. Using that relation, the induced polarization can be written as $P = dY_e \times strain$, while the stress required to keep the strain constant when the crystal is in an electric field is $stress = -dY_eE$. The strain in a deformed elastic body is the fractional change in the dimensions of the body in various directions; the stress is the internal pressure along the various directions. Both are second-rank tensors, and, since electric field and polarization are vectors, the detailed treatment of piezoelectricity is complex. The equations above are oversimplified but can be used for crystals in certain orientations.

The polarization effects responsible for piezoelectricity arise from small displacements of ions in the crystal lattice. Such an effect is not found in crystals with a centre of symmetry. The direct effect can be quite strong; a potential $V = Y_e d\delta/\varepsilon_0 K$ is generated in a crystal compressed by an amount δ, where K is the dielectric constant. If lead zirconate titanate is placed between two electrodes and a pressure causing a reduction of only 1/20th of one millimetre is applied, a 100,000-volt potential is produced. The direct effect is used, for example, to generate an electric spark with which to ignite natural gas in a heating unit or an outdoor cooking grill.

In practice, the converse piezoelectric effect, which occurs when an external electric field changes the dimensions of a crystal, is small because the electric fields that can be generated in a laboratory are minuscule compared to those existing naturally in matter. A static electric field of 10^6 volts per metre produces a change of only about 0.001 millimetre in the length of a one-centimetre quartz crystal. The effect can be enhanced by the application of an alternating electric field of the same frequency as the natural mechanical vibration frequency of the crystal. Many of the crystals have a quality factor Q of several hundred, and, in the case of quartz, the value can be 10^6. The result is a piezoelectric coefficient a factor Q higher than for a static electric field. The very large Q of quartz is exploited in electronic oscillator circuits to make remarkably accurate timepieces. The mechanical vibrations that can be induced in a crystal by the converse piezoelectric effect are also used to generate ultrasound, which is sound with a frequency far higher than frequencies audible to the human ear—above 20 kilohertz. The reflected sound is detectable by the direct effect. Such effects form the basis of ultrasound systems used to fathom the depths of lakes and waterways and to locate fish. Ultrasound has found application in medical imaging (*e.g.*, fetal monitoring and the detection of abnormalities such as prostate tumours). The use of ultrasound makes it possible to produce detailed pictures of organs and other internal structures because of the variation in the reflection of sound from various body tissues. Thin films of polymeric plastic with a piezoelectric coefficient of about 10^{-11} metres per volt are being developed and have numerous potential applications as pressure transducers.

Generation of ultrasound

ELECTRO-OPTIC PHENOMENA

The index of refraction n of a transparent substance is related to its electric polarizability and is given by $n^2 = 1 + \chi_e/\varepsilon_0$. As discussed earlier, χ_e is the electric susceptibility of a medium, and the equation $P = \chi_e E$ relates the polarization of the medium to the applied electric field. For most matter, χ_e is not a constant independent of the value of the electric field, but rather depends to a small degree on the value of the field. Thus, the index of

refraction can be changed by applying an external electric field to a medium. In liquids, glasses, and crystals that have a centre of symmetry, the change is usually very small. Called the Kerr effect (for its discoverer, the Scottish physicist John Kerr), it is proportional to the square of the applied electric field. In noncentrosymmetric crystals, the change in the index of refraction n is generally much greater; it depends linearly on the applied electric field and is known as the Pockels effect (after the German physicist F. R. Pockels).

Modulation of the index of refraction

A varying electric field applied to a medium will modulate its index of refraction. This change in the index of refraction can be used to modulate light and make it carry information. A crystal widely used for its Pockels effect is potassium dihydrogen phosphate, which has good optical properties and low dielectric losses even at microwave frequencies.

An unusually large Kerr effect is found in nitrobenzene, a liquid with highly "acentric" molecules that have large electric dipole moments. Applying an external electric field partially aligns the otherwise randomly oriented dipole moments and greatly enhances the influence of the field on the index of refraction. The length of the path of light through nitrobenzene can be adjusted easily because it is a liquid.

THERMOELECTRICITY

When two metals are placed in electric contact, electrons flow out of the one in which the electrons are less bound and into the other. The binding is measured by the location of the so-called Fermi level of electrons in the metal; the higher the level, the lower is the binding. The Fermi level represents the demarcation in energy within the conduction band of a metal between the energy levels occupied by electrons and those that are unoccupied. The energy of an electron at the Fermi level is $-W$ relative to a free electron outside the metal. The flow of electrons between the two conductors in contact continues until the change in electrostatic potential brings the Fermi levels of the two metals (W_1 and W_2) to the same value. This electrostatic potential is called the contact potential φ_{12} and is given by $e\varphi_{12} = W_1 - W_2$, where e is 1.6×10^{-19} coulomb.

If a closed circuit is made of two different metals, there will be no net electromotive force in the circuit because the two contact potentials oppose each other and no current will flow. There will be a current if the temperature of one of the junctions is raised with respect to that of the second.

Generation of a thermal electromotive force

There is a net electromotive force generated in the circuit, as it is unlikely that the two metals will have Fermi levels with identical temperature dependence. To maintain the temperature difference, heat must enter the hot junction and leave the cold junction; this is consistent with the fact that the current can be used to do mechanical work. The generation of a thermal electromotive force at a junction is called the Seebeck effect (after the Estonian-born German physicist Thomas Johann Seebeck). The electromotive force is approximately linear with the temperature difference between two junctions of dissimilar metals, which are called a thermocouple. For a thermocouple made of iron and constantan (an alloy of 60 percent copper and 40 percent nickel), the electromotive force is about five millivolts when the cold junction is at 0° C and the hot junction at 100° C. One of the principal applications of the Seebeck effect is the measurement of temperature. The chemical properties of the medium, the temperature of which is measured, and the sensitivity required dictate the choice of components of a thermocouple.

The absorption or release of heat at a junction in which there is an electric current is called the Peltier effect (after the French physicist Jean-Charles Peltier). Both the Seebeck and Peltier effects also occur at the junction between a metal and a semiconductor and at the junction between two semiconductors. The development of semiconductor thermocouples (*e.g.*, those consisting of *n*-type and *p*-type bismuth telluride) has made the use of the Peltier effect practical for refrigeration. Sets of such thermocouples are connected electrically in series and thermally in parallel. When an electric current is made to flow, a temperature difference, which depends on the current, develops between the two junctions. If the temperature of the hotter junction is kept low by removing heat, the second junction can be tens of degrees colder and act as a refrigerator. Peltier refrigerators are used to cool small bodies; they are compact, have no moving mechanical parts, and can be regulated to maintain precise and stable temperatures. They are employed in numerous applications, as, for example, to keep the temperature of a sample constant while it is on a microscope stage.

THERMIONIC EMISSION

A metal contains mobile electrons in a partially filled band of energy levels—*i.e.*, the conduction band. These electrons, though mobile within the metal, are rather tightly bound to it. The energy that is required to release a mobile electron from the metal varies from about 1.5 to approximately six electron volts, depending on the metal. In thermionic emission, some of the electrons acquire enough energy from thermal collisions to escape from the metal. The number of electrons emitted and therefore the thermionic emission current depend critically on temperature.

In a metal the conduction-band levels are filled up to the Fermi level, which lies at an energy $-W$ relative to a free electron outside the metal. The work function of the metal, which is the energy required to remove an electron from the metal, is therefore equal to W. At a temperature of 1,000 K only a small fraction of the mobile electrons have sufficient energy to escape. The electrons that can escape are moving so fast in the metal and have such high kinetic energies that they are unaffected by the periodic potential caused by atoms of the metallic lattice. They behave like electrons trapped in a region of constant potential. Because of this, when the rate at which electrons escape from the metal is calculated, the detailed structure of the metal has little influence on the final result. A formula known as Richardson's law (first proposed by the English physicist Owen W. Richardson) is roughly valid for all metals. It is usually expressed in terms of the emission current density (J) as

$$J = AT^2 e^{-W/kT}$$

in amperes per square metre. The Boltzmann constant k has the value 8.62×10^{-5} electron volts per kelvin, and temperature T is in kelvins. The constant A is 1.2×10^6 ampere degree squared per square metre, and varies slightly for different metals. For tungsten, which has a work function W of 4.5 electron volts, the value of A is 7×10^5 amperes per square metre kelvin squared and the current density at T equaling 2,400 K is 0.14 ampere per square centimetre. J rises rapidly with temperature. If T is increased to 2,600 K, J rises to 0.9 ampere per square centimetre. Tungsten does not emit appreciably at 2,000 K or below (less than 0.05 milliampere per square centimetre) because its work function of 4.5 electron volts is large compared to the thermal energy kT, which is only 0.16 electron volt. In vacuum tubes, the cathode usually is coated with a mixture of barium and strontium oxides. At 1,000 K the oxide has a work function of approximately 1.3 electron volts and is a reasonably good conductor. Currents of several amperes per square centimetre can be drawn from oxide cathodes, but in practice the current density is generally less than 0.2 ampere per square centimetre. The oxide layer deteriorates rapidly when higher current densities are drawn.

SECONDARY ELECTRON EMISSION

If electrons with energies of 10 to 1,000 electron volts strike a metal surface in a vacuum, their energy is lost in collisions in a region near the surface, and most of it is transferred to other electrons in the metal. Because this occurs near the surface, some of these electrons may be ejected from the metal and form a secondary emission current. The ratio of secondary electrons to incident electrons is known as the secondary emission coefficient. For low-incident energies (below about one electron volt), the primary electrons tend to be reflected and the secondary emission coefficient is near unity. With increasing energy, the coefficient at first falls and then at about 10 elec-

tron volts begins to rise again, usually reaching a peak of value between 2 and 4 at energies of a few hundred electron volts. At higher energies, the primary electrons penetrate so far below the surface before losing energy that the excited electrons have little chance of reaching the surface and escaping. The secondary emission coefficients fall and, when the electrons have energies exceeding 20 kiloelectron volts, are usually well below unity. Secondary emission also can occur in insulators. Because many insulators have rather high secondary emission coefficients, it is often useful when high secondary emission yields are required to coat a metal electrode with a thin insulator layer a few atoms thick.

PHOTOELECTRIC CONDUCTIVITY

If light with a photon energy $h\nu$ that exceeds the work function W falls on a metal surface, some of the incident photons will transfer their energy to electrons, which then will be ejected from the metal. Since $h\nu$ is greater than W, the excess energy $h\nu - W$ transferred to the electrons will be observed as their kinetic energy outside the metal. The relation between electron kinetic energy E and the frequency ν (that is, $E = h\nu - W$) is known as the Einstein relation, and its experimental verification helped to establish the validity of quantum theory. The energy of the electrons depends on the frequency of the light, while the intensity of the light determines the rate of photoelectric emission.

In a semiconductor the valence band of energy levels is almost completely full while the conduction band is almost empty. The conductivity of the material derives from the few holes present in the valence band and the few electrons in the conduction band. Electrons can be excited from the valence to the conduction band by light photons having an energy $h\nu$ that is larger than energy gap E_g between the bands. The process is an internal photoelectric effect. The value of E_g varies from semiconductor to semiconductor. For lead sulfide, the threshold frequency occurs in the infrared, whereas for zinc oxide it is in the ultraviolet. For silicon, E_g equals 1.1 electron volts, and the threshold wavelength is in the infrared, about 1,100 nanometres. Visible radiation produces electron transitions with almost unity quantum efficiency in silicon. Each transition yields a hole–electron pair (*i.e.,* two carriers) that contributes to electric conductivity. For example, if one milliwatt of light strikes a sample of pure silicon in the form of a thin plate one square centimetre in area and 0.03 centimetre thick (which is thick enough to absorb all incident light), the resistance of the plate will be decreased by a factor of about 1,000. In practice, photoconductive effects are not usually as large as this, but this example indicates that appreciable changes in conductivity can occur even with low illumination. Photoconductive devices are simple to construct and are used to detect visible, infrared, and ultraviolet radiation.

Internal photoelectric effect

ELECTROLUMINESCENCE

Conduction electrons moving in a solid under the influence of an electric field usually lose kinetic energy in low-energy collisions as fast as they acquire it from the field. Under certain circumstances in semiconductors, however, they can acquire enough energy between collisions to excite atoms in the next collision and produce radiation as the atoms de-excite. A voltage applied across a thin layer of zinc sulfide powder causes just such an electroluminescent effect. Electroluminescent panels are of more interest as signal indicators and display devices than as a source of general illumination.

A somewhat similar effect occurs at the junction in a reverse-biased semiconductor p–n junction diode—*i.e.,* a p–n junction diode in which the applied potential is in the direction of small current flow. Electrons in the intense field at the depleted junction easily acquire enough energy to excite atoms. Little of this energy finally emerges as light, though the effect is readily visible under a microscope.

When a junction between a heavily doped n-type material and a less doped p-type material is forward-biased so that a current will flow easily, the current consists mainly of electrons injected from the n-type material into the conduction band of the p-type material. These electrons ultimately drop into holes in the valence band and release energy equal to the energy gap of the material. In most cases, this energy E_g is dissipated as heat, but in gallium phosphide and especially in gallium arsenide, an appreciable fraction appears as radiation, the frequency ν of which satisfies the relation $h\nu = E_g$. In gallium arsenide, though up to 30 percent of the input electric energy is available as radiation, the characteristic wavelength of 900 nanometres is in the infrared. Gallium phosphide gives off visible green light but is inefficient; other related III-V compound semiconductors emit light of different colours. Electroluminescent injection diodes of such materials, commonly known as light-emitting diodes (LEDs), are employed mainly as indicator lamps and numeric displays. Semiconductor lasers built with layers of indium phosphide and of gallium indium arsenide phosphide have proved more useful. Unlike gas or optically pumped lasers, these semiconductor lasers can be modulated directly at high frequencies. Not only are they used in devices such as compact digital disc players but also as light sources for long-distance optical fibre communications systems (see ELECTRONICS: *Light-emitting diodes and semiconductor lasers*).

BIOELECTRIC EFFECTS

Bioelectricity refers to the generation or action of electric currents or voltages in biological processes. Bioelectric phenomena include fast signaling in nerves and the triggering of physical processes in muscles or glands. There is some similarity among the nerves, muscles, and glands of all organisms, possibly because fairly efficient electrochemical systems evolved early. Scientific studies tend to focus on the following: nerve or muscle tissue; such organs as the heart, brain, eye, ear, stomach, and certain glands; electric organs in some fish; and potentials associated with damaged tissue.

Electric activity in living tissue is a cellular phenomenon, dependent on the cell membrane. The membrane acts like a capacitor, storing energy as electrically charged ions on opposite sides of the membrane. The stored energy is available for rapid utilization and stabilizes the membrane system so that it is not activated by small disturbances.

Cells capable of electric activity show a resting potential in which their interiors are negative by about 0.1 volt or less compared with the outside of the cell. When the cell is activated, the resting potential may reverse suddenly in sign; as a result, the outside of the cell becomes negative and the inside positive. This condition lasts for a short time, after which the cell returns to its original resting state. This sequence, called depolarization and repolarization, is accompanied by a flow of substantial current through the active cell membrane, so that a "dipole-current source" exists for a short period. Small currents flow from this source through the aqueous medium containing the cell and are detectable at considerable distances from it. These currents, originating in active membrane, are functionally significant very close to their site of origin but must be considered incidental at any distance from it. In electric fish, however, adaptations have occurred, and this otherwise incidental electric current is actually utilized. In some species the external current is apparently used for sensing purposes, while in others it is used to stun or kill prey. In both cases, voltages from many cells add up in series, thus assuring that the specialized functions can be performed. Bioelectric potentials detected at some distance from the cells generating them may be as small as the 20 or 30 microvolts associated with certain components of the human electroencephalogram or the millivolt of the human electrocardiogram. On the other hand, electric eels can deliver electric shocks with voltages as large as 1,000 volts.

Depolarization and repolarization in cells

In addition to the potentials originating in nerve or muscle cells, relatively steady or slowly varying potentials (often designated dc) are known. These dc potentials occur in the following cases: in areas where cells have been damaged and where ionized potassium is leaking (as much as 50 millivolts); when one part of the brain is compared with another part (up to one millivolt); when different areas of the skin are compared (up to 10 millivolts); within pockets in active glands, *e.g.,* follicles in the thyroid (as

high as 60 millivolts); and in special structures in the inner ear (about 80 millivolts).

A small electric shock caused by static electricity during cold, dry weather is a familiar experience. While the sudden muscular reaction it engenders is sometimes unpleasant, it is usually harmless. Even though static potentials of several thousand volts are involved, a current exists for only a brief time and the total charge is very small. A steady current of two milliamperes through the body is barely noticeable. Severe electrical shock can occur above 10 milliamperes, however. Lethal current levels range from 100 to 200 milliamperes. Larger currents, which produce burns and unconsciousness, are not fatal if the victim is given prompt medical care. (Above 200 milliamperes, the heart is clamped during the shock and does not undergo ventricular fibrillation.) Prevention clearly includes avoiding contact with live electric wiring; risk of injury increases considerably if the skin is wet, as the electric resistance of wet skin may be hundreds of times smaller than that of dry skin. (F.N.H.R./E.E.S./E.Ka.)

Magnetic properties of matter

All matter exhibits magnetic properties when placed in an external magnetic field. Even substances like copper and aluminum that are not normally thought of as having magnetic properties are affected by the presence of a magnetic field such as that produced by either pole of a bar magnet. Depending on whether there is an attraction or repulsion by the pole of a magnet, matter is classified as being either paramagnetic or diamagnetic, respectively. A few materials, notably iron, show a very large attraction toward the pole of a permanent bar magnet; materials of this kind are called ferromagnetic.

Classification of matter as paramagnetic, diamagnetic, or ferromagnetic

In 1845 Faraday became the first to classify substances as either diamagnetic or paramagnetic. He based this classification on his observation of the force exerted on substances in an inhomogeneous magnetic field. At moderate field strengths, the magnetization M of a substance is linearly proportional to the strength of the applied field H. The magnetization is specified by the magnetic susceptibility χ (previously labeled χ_m), defined by the relation $M = \chi H$. A sample of volume V placed in a field H directed in the x-direction and increasing in that direction at a rate dH/dx will experience a force in the x-direction of $F = \chi\mu_0 VH\,(dH/dx)$. If the magnetic susceptibility χ is positive, the force is in the direction of increasing field strength, whereas if χ is negative, it is in the direction of decreasing field strength. Measurement of the force F in a known field H with a known gradient dH/dx is the basis of a number of accurate methods of determining χ.

Substances for which the magnetic susceptibility is negative (*e.g.*, copper and silver) are classified as diamagnetic. The susceptibility is small, on the order of -10^{-5} for solids and liquids and -10^{-8} for gases. A characteristic feature of diamagnetism is that the magnetic moment per unit mass in a given field is virtually constant for a given substance over a very wide range of temperatures. It changes little between solid, liquid, and gas; the variation in the susceptibility between solid or liquid and gas is almost entirely due to the change in the number of molecules per unit volume. This indicates that the magnetic moment induced in each molecule by a given field is primarily a property characteristic of the molecule.

Substances for which the magnetic susceptibility is positive are classed as paramagnetic. In a few cases (including most metals), the susceptibility is independent of temperature, but in most compounds it is strongly temperature dependent, increasing as the temperature is lowered. Measurements by the French physicist Pierre Curie in 1895 showed that for many substances the susceptibility is inversely proportional to the absolute temperature T; that is, $\chi = C/T$. This approximate relationship is known as Curie's law and the constant C as the Curie constant. A more accurate equation is obtained in many cases by modifying the above equation to $\chi = C/(T - \theta)$, where θ is a constant. This equation is called the Curie–Weiss law (after Curie and Pierre-Ernest Weiss, another French physicist). From the form of this last equation, it is clear that at the temperature $T = \theta$, the value of the susceptibility becomes infinite. Below this temperature, the material exhibits spontaneous magnetization—*i.e.*, it becomes ferromagnetic. Its magnetic properties are then very different from those in the paramagnetic or high-temperature phase. In particular, although its magnetic moment can be changed by the application of a magnetic field, the value of the moment attained in a given field is not always the same; it depends on the previous magnetic, thermal, and mechanical treatment of the sample.

Curie–Weiss law

INDUCED AND PERMANENT ATOMIC MAGNETIC DIPOLES

Whether a substance is paramagnetic or diamagnetic is determined primarily by the presence or absence of free magnetic dipole moments (*i.e.*, those free to rotate) in its constituent atoms. When there are no free moments, the magnetization is produced by currents of the electrons in their atomic orbits. The substance is then diamagnetic, with a negative susceptibility independent of both field strength and temperature.

In matter with free magnetic dipole moments, the orientation of the moments is normally random and, as a result, the substance has no net magnetization. When a magnetic field is applied, the dipoles are no longer completely randomly oriented; more dipoles point with the field than against the field. When this results in a net positive magnetization in the direction of the field, the substance has a positive susceptibility and is classified as paramagnetic.

The forces opposing alignment of the dipoles with the external magnetic field are thermal in origin and thus weaker at low temperatures. The excess number of dipoles pointing with the field is determined by (mB/kT), where mB represents the magnetic energy and kT the thermal energy. When the magnetic energy is small compared to the thermal energy, the excess number of dipoles pointing with the field is proportional to the field and inversely proportional to the absolute temperature, corresponding to Curie's law. When the value of (mB/kT) is large enough to align nearly all the dipoles with the field, the magnetization approaches a saturation value.

There is a third category of matter in which intrinsic moments are not normally present but appear under the influence of an external magnetic field. The intrinsic moments of conduction electrons in metals behave this way. One finds a small positive susceptibility independent of temperature comparable with the diamagnetic contribution, so that the overall susceptibility of a metal may be positive or negative. The molar susceptibility of elements is shown in Figure 43.

Mutual forces between dipoles

In addition to the forces exerted on atomic dipoles by an external magnetic field, mutual forces exist between the dipoles. Such forces vary widely for different substances. Below a certain transition temperature depending on the substance, they produce an ordered arrangement of the orientations of the atomic dipoles even in the absence of an external field. The mutual forces tend to align neighbouring dipoles either parallel or antiparallel to one another. Parallel alignment of atomic dipoles throughout large volumes of the substance results in ferromagnetism, with a permanent magnetization on a macroscopic scale. On the other hand, if equal numbers of atomic dipoles are aligned in opposite directions and the dipoles are of the same size, there is no permanent macroscopic magnetization, and this is known as antiferromagnetism. If the atomic dipoles are of different magnitudes and those pointing in one direction are all different in size from those pointing in the opposite direction, there exists permanent magnetization on a macroscopic scale in an effect known as ferrimagnetism. A simple schematic representation of these different possibilities is shown in Figure 44.

In all cases, the material behaves as a paramagnet above the characteristic transition temperature; it acquires a macroscopic magnetic moment only when an external field is applied.

DIAMAGNETISM

When an electron moving in an atomic orbit is in a magnetic field B, the force exerted on the electron pro-

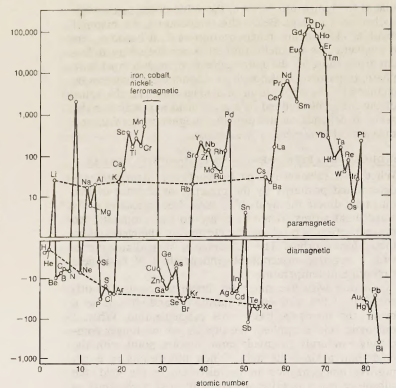

Figure 43: The susceptibility of a kilogram mole of the elements. Broken lines connect the alkali metals (paramagnetic) and the rare gases of the atmosphere (diamagnetic).

duces a small change in the orbital motion; the electron orbit precesses about the direction of B. As a result, each electron acquires an additional angular momentum that contributes to the magnetization of the sample. The susceptibility χ is given by

$$\chi = -\mu_0 N \left(\frac{e^2}{6m}\right) \Sigma < r^2 >,$$

where $\Sigma < r^2 >$ is the sum of the mean square radii of all electron orbits in each atom, e and m are the charge and mass of the electron, and N is the number of atoms per unit volume. The negative sign of this susceptibility is a direct consequence of Lenz's law (see above). When B is switched on, the change in motion of each orbit is equivalent to an induced circulating electric current in such a direction that its own magnetic flux opposes the change in magnetic flux through the orbit; *i.e.*, the induced magnetic moment is directed opposite to B.

Since the magnetization M is proportional to the number N of atoms per unit volume, it is sometimes useful to give the susceptibility per mole, χ_{mole}. For a kilogram mole (the molecular weight in kilograms), the numerical value of the molar susceptibility is

$$\chi_{mole} = -3.55 \times 10^{12} \Sigma < r^2 >.$$

For an atom, the mean value of $\Sigma < r^2 >$ is about 10^{-21} square metre and χ_{mole} has values of 10^{-9} to 10^{-10}; the atomic number Z equals the number of electrons in each atom. The quantity $\Sigma < r^2 >$ for each atom, and therefore the diamagnetic susceptibility, is essentially independent of temperature. It is also not affected by the surroundings of the atom.

A different kind of diamagnetism occurs in superconductors. The conduction electrons are spread out over the entire metal, and so the induced magnetic moment is governed by the size of the superconducting sample rather than by the size of the individual constituent atoms (a very large effective $< r^2 >$). The diamagnetism is so strong that the magnetic field is kept out of the superconductor.

Diamagnetism in superconductors

PARAMAGNETISM

Paramagnetism occurs primarily in substances in which some or all of the individual atoms, ions, or molecules possess a permanent magnetic dipole moment. The magnetization of such matter depends on the ratio of the magnetic energy of the individual dipoles to the thermal energy. This dependence can be calculated in quantum theory and is given by the Brillouin function, which depends only on the ratio (B/T). At low magnetic fields, the magnetization is linearly proportional to the field and reaches its maximum saturation value when the magnetic energy is much greater than the thermal energy. Figure 45 shows the dependence of the magnetic moment per ion in units of Bohr magnetons as a function of B/T. (One Bohr magneton equals 9.274×10^{-24} ampere times square metre.)

In substances that have a nuclear magnetic dipole moment, there is a further contribution to susceptibility. The size of the nuclear magnetic moment is only about one-thousandth that of an atom. Per kilogram mole, χ_n is on the order of $10^{-8}/T$; in solid hydrogen this just exceeds the electronic diamagnetism of 1 K.

Curie's law should hold when mB is much smaller than kT, provided that no other forces act on the atomic dipoles. In many solids, the presence of internal forces may cause the susceptibility to vary in a complicated way. If the forces orient the dipoles parallel to each other, the behaviour is ferromagnetic (see below). The forces may orient the dipoles so that the normal state has no free moment. If the force is sufficiently weak, a small magnetic field can reorient the dipoles, resulting in a net magnetization. This type of paramagnetism occurs for conduction electrons in a metal. In normal metals, each occupied electron state has two electrons with opposite spin orientation. This is a consequence of the Pauli principle of quantum mechanics, which permits no greater occupancy of the energetically favoured states. In the presence of a magnetic field, however, it is energetically more favourable for some of the electrons to move to higher states. With only single electrons in these states, the electron moments can be oriented along the field. The resulting paramagnetic susceptibility is independent of temperature. The net susceptibility is independent of temperature. The net susceptibility of a metal can be of either sign, since the diamagnetic and paramagnetic contributions are of comparable magnitudes.

By courtesy of *Electrical Engineering*

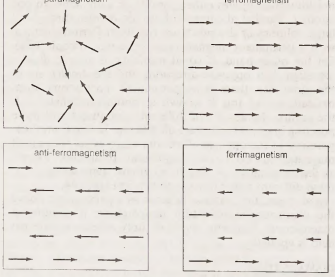

Figure 44: Arrangement of the atomic dipoles in different types of magnetic materials.

FERROMAGNETISM

A ferromagnetic substance contains permanent atomic magnetic dipoles that are spontaneously oriented parallel to one another even in the absence of an external field. The magnetic repulsion between two dipoles aligned side by side with their moments in the same direction makes it difficult to understand the phenomenon of ferromagnetism. It is known that within a ferromagnetic material, there is a spontaneous alignment of atoms in large clusters. A new type of interaction, a quantum mechanical effect known as the exchange interaction, is involved. A highly simplified description of how the exchange interaction aligns electrons in ferromagnetic materials is given here.

Role of the exchange interaction

The magnetic properties of iron are thought to be the result of the magnetic moment associated with the spin

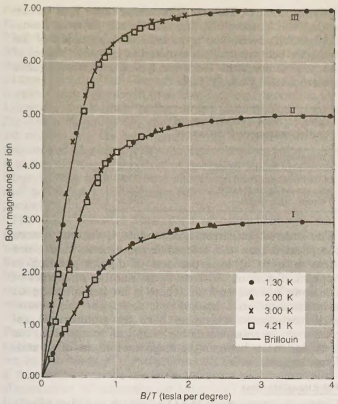

Figure 45: *The approach to saturation in the magnetization of a paramagnetic substance following a Brillouin curve.* The curves I, II, and III refer to ions of chromium, potassium alum, iron ammonium alum, and gadolinium sulfate octahydrate for which $g = 2$ and $j = 3/2$, 5/2, and 7/2, respectively.

of an electron in an outer atomic shell—specifically, the third *d* shell. Such electrons are referred to as magnetization electrons. The Pauli exclusion principle prohibits two electrons from having identical properties; for example, no two electrons can be in the same location and have spins in the same direction. This exclusion can be viewed as a "repulsive" mechanism for spins in the same direction; its effect is opposite that required to align the electrons responsible for the magnetization in the iron domains. However, other electrons with spins in the opposite direction, primarily in the fourth *s* atomic shell, interact at close range with the magnetization electrons, and this interaction is attractive. Because of the attractive effect of their opposite spins, these *s*-shell electrons influence the magnetization electrons of a number of the iron atoms and align them with each other.

A simple empirical representation of the effect of such exchange forces invokes the idea of an effective internal, or molecular, field H_{int}, which is proportional in size to the magnetization M; that is, $H_{int} = \lambda M$ in which λ is an empirical parameter. The resulting magnetization M equals $\chi_p(H + \lambda M)$, in which χ_p is the susceptibility that the substance would have in the absence of the internal field. Assuming that $\chi_p = C/T$, corresponding to Curie's law, the equation $M = C(H + \lambda M)/T$ has the solution $\chi = M/H = C/(T - C\lambda) = C/(T - Tc)$. This result, the Curie–Weiss law, is valid at temperatures greater than the Curie temperature T_c (see below); at such temperatures the substance is still paramagnetic because the magnetization is zero when the field is zero. The internal field, however, makes the susceptibility larger than that given by the Curie law. A plot of $1/\chi$ against T still gives a straight line, as shown in Figure 46, but $1/\chi$ becomes zero when the temperature reaches the Curie temperature.

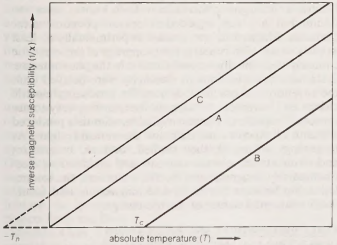

Figure 46: Plot of $1/\chi$. (A) Curie's law. (B) Curie–Weiss law for a ferromagnet with Curie temperature T_c. (C) Curie–Weiss law for an antiferromagnetic substance.

Since $1/\chi = H/M$, M at this temperature must be finite even when the magnetic field is zero. Thus, below the Curie temperature, the substance exhibits a spontaneous magnetization M in the absence of an external field, the essential property of a ferromagnet. Table 4 gives Curie temperature values for various ferromagnetic substances.

Curie temperature as the point of transition

Table 4: Curie Temperatures for Some Ferromagnetic Substances	
Iron (Fe)	1,043 K
Cobalt (Co)	1,394 K
Nickel (Ni)	631 K
Gadolinium (Gd)	293 K
"Bismanol" (MnBi)	633 K
Manganese arsenide (MnAs)	318 K

In the ferromagnetic phase below the Curie temperature, the spontaneous alignment is still resisted by random thermal energy, and the spontaneous magnetization M is a function of temperature. The magnitude of M can be found from the paramagnetic equation for the reduced magnetization $M/M_s = f(mB/kT)$ by replacing B with $\mu(H + \lambda M)$. This gives an equation that can be solved numerically if the function f is known. When H equals zero, the curve of (M/M_s) should be a unique function of the ratio (T/T_c) for all substances that have the same function f. Such a curve is shown in Figure 47, together with experimental results for nickel and a nickel–copper alloy.

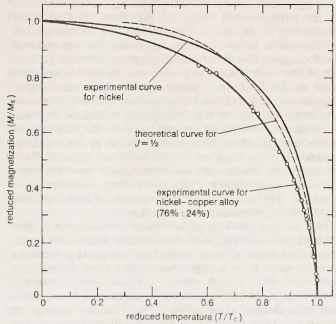

Figure 47: The reduced magnetization M/M_s as a function of reduced temperature T/T_c for a magnet.

The molecular field theory explains the existence of a ferromagnetic phase and the presence of spontaneous magnetization below the Curie temperature. The dependence of the magnetization on the external field is, however, more complex than the Curie–Weiss theory predicts. The magnetization curve is shown in Figure 48 for iron, with the field B in the iron plotted against the external field H. The variation is nonlinear, and B reaches its saturation value S in small fields. The relative permeability $B/\mu_0 H$ attains values of 10^3 to 10^4 in contrast to an ordinary paramagnet, for which μ is about 1.001 at room temperature. On reducing the external field H, the field B does not return along the magnetization curve. Even at $H = 0$, its value is not far below the saturation value.

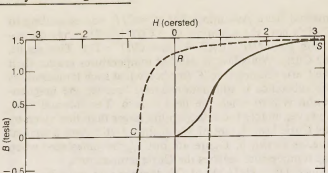

Figure 48: The magnetization curve (solid curve) and hysteresis loop (broken curve) for a ferromagnet.

When $H = 0$ (labeled R in the figure), the magnetic field constitutes what is termed the residual flux density, and the retention of magnetization in zero field is called remanence. When the external field is reversed, the value of B falls and passes through zero (point C) at a field strength known as the coercive force. Further increase in the reverse field H sets up a reverse field B that again quickly reaches a saturation value S'. Finally, as the reverse field is removed and a positive field applied, B traces out the lower broken line back to a positive saturation value. Further cycles of H retrace the broken curve, which is known as the hysteresis curve, because the change in B always lags behind the change in H. The hysteresis curve is not unique unless saturation is attained in each direction; interruption and reversal of the cycle at an intermediate field strength results in a hysteresis curve of smaller size.

Remanence

To explain ferromagnetic phenomena, Weiss suggested that a ferromagnetic substance contains many small regions (called domains), in each of which the substance is magnetized locally to saturations in some direction. In the unmagnetized state, such directions are distributed at random or in such a way that the net magnetization of the whole sample is zero. Application of an external field changes the direction of magnetization of part or all of the domains, setting up a net magnetization parallel to the field. In a paramagnetic substance, atomic dipoles are oriented on a microscopic scale. In contrast, the magnetization of a ferromagnetic substance involves the reorientation of the magnetization of the domains on a macroscopic scale; large changes occur in the net magnetization even when very small fields are applied. Such macroscopic changes are not immediately reversed when the size of the field is reduced or when its direction is changed. This accounts for the presence of hysteresis and for the finite remanent magnetization.

The technological applications of ferromagnetic substances are extensive, and the size and shape of the hysteresis curve are of great importance. A good permanent magnet must have a large spontaneous magnetization in zero field (*i.e.*, a high retentivity) and a high coercive force to prevent its being easily demagnetized by an external field. Both of these imply a "fat," almost rectangular hysteresis loop, typical of a hard magnetic material. On the other hand, ferromagnetic substances subjected to alternating fields, as in a transformer, must have a "thin" hysteresis loop because of an energy loss per cycle that is determined by the area enclosed by the hysteresis loop. Such substances are easily magnetized and demagnetized and are known as soft magnetic materials.

ANTIFERROMAGNETISM

Differences between ferromagnetic and antiferromagnetic substances

In substances known as antiferromagnets, the mutual forces between pairs of adjacent atomic dipoles are caused by exchange interactions, but the forces between adjacent atomic dipoles have signs opposite those in ferromagnets. As a result, adjacent dipoles tend to line up antiparallel to each other instead of parallel. At high temperatures the material is paramagnetic, but below a certain characteristic temperature the dipoles are aligned in an ordered and antiparallel manner. The transition temperature T_n is known as the Néel temperature, after the French physicist Louis-Eugène-Félix Néel, who proposed this explanation of the magnetic behaviour of such materials in 1936. Values of the Néel temperature for some typical antiferromagnetic substances are given in Table 5.

Table 5: Néel Temperature of Antiferromagnetic Substances

Chromium (Cr)	311 K
Manganese fluoride (MnF_2)	67 K
Nickel fluoride (NiF_2)	73 K
Manganese oxide (MnO)	116 K
Ferrous oxide (FeO)	198 K

The ordered antiferromagnetic state is naturally more complicated than the ordered ferromagnetic state, since there must be at least two sets of dipoles pointing in opposite directions. With an equal number of dipoles of the same size on each set, there is no net spontaneous magnetization on a macroscopic scale. For this reason, antiferromagnetic substances have few commercial applications. In most insulating chemical compounds, the exchange forces between the magnetic ions are of an antiferromagnetic nature.

FERRIMAGNETISM

Lodestone, or magnetite (Fe_3O_4), belongs to a class of substances known as ferrites. Ferrites and some other classes of magnetic substances discovered more recently possess many of the properties of ferromagnetic materials, including spontaneous magnetization and remanence. Unlike the ferromagnetic metals, they have low electric conductivity, however. In alternating magnetic fields, this greatly reduces the energy loss resulting from eddy currents. Since these losses rise with the frequency of the alternating field, such substances are of much importance in the electronics industry.

Low electric conductivity of ferrites

A notable property of ferrites and associated materials is that the bulk spontaneous magnetization, even at complete magnetic saturation, does not correspond to the value expected if all the atomic dipoles are aligned parallel to each other. The explanation was put forward in 1948 by Néel, who suggested that the exchange forces responsible for the spontaneous magnetization were basically antiferromagnetic in nature and that in the ordered state they contained two (or more) sublattices spontaneously magnetized in opposite directions. In contrast to the simple antiferromagnetic substances considered above, however, the sizes of the magnetization on the two sublattices are unequal, giving a resultant net magnetization parallel to that of the sublattice with the larger moment. For this phenomenon Néel coined the name ferrimagnetism, and substances that exhibit it are called ferrimagnetic materials.

(B.Ble./E.Ka./S.McG.)

Historical survey

Electric and magnetic forces have been known since antiquity, but they were regarded as separate phenomena for centuries. Magnetism was studied experimentally at least as early as the 13th century; the properties of the magnetic compass undoubtedly aroused interest in the phenomenon. Systematic investigations of electricity were delayed until the invention of practical devices for producing electric charge and currents. As soon as inexpensive, easy-to-use sources of electricity became available, scientists produced a wealth of experimental data and theoretical insights. As technology advanced, they studied, in turn, magnetism and electrostatics, electric currents and conduction, electrochemistry, magnetic and electric induction, the interrelationship between electricity and magnetism, and finally the fundamental nature of electric charge.

EARLY OBSERVATIONS AND APPLICATIONS OF ELECTRIC AND MAGNETIC PHENOMENA

The ancient Greeks knew about the attractive force of both magnetite and rubbed amber. Magnetite, a magnetic

oxide of iron mentioned in Greek texts as early as 800 BC, was mined in the province of Magnesia in Thessaly. Thales of Miletus, who lived nearby, may have been the first Greek to study magnetic forces. He apparently knew that magnetite attracts iron and that rubbing amber (a fossil tree resin that the Greeks called *élektron*) would make it attract such lightweight objects as feathers. According to Lucretius, the Roman author of the philosophical poem *De rerum natura* ("On the Nature of Things") in the 1st century BC, the term magnet was derived from the province of Magnesia. Pliny the Elder, however, attributes it to the supposed discoverer of the mineral, the shepherd Magnes, "the nails of whose shoes and the tip of whose staff stuck fast in a magnetic field while he pastured his flocks."

The magnetic compass

The oldest practical application of magnetism was the magnetic compass, but its origin remains unknown. Some historians believe it was used in China as far back as the 26th century BC; others contend that it was invented by the Italians or Arabs and introduced to the Chinese during the 13th century AD. The earliest extant European reference is by Alexander Neckam (*d.* 1217) of England.

The first experiments with magnetism are attributed to Petrus Peregrinus de Maricourt, a French crusader and engineer. In his oft-cited *Epistola de magnete* (1269; "Letter on the Magnet"), Peregrinus describes having placed a thin iron rectangle on different parts of a spherically shaped piece of magnetite (or lodestone) and marked the lines along which it set itself. The lines formed a set of meridians of longitude passing through two points at opposite ends of the stone, in much the same way as the lines of longitude on the Earth's surface intersect at the North and South poles. By analogy, Peregrinus called the points the poles of the magnet. He further noted that, when a magnet is cut into pieces, each piece still has two poles. He also observed that unlike poles attract each other and that a strong magnet can reverse the polarity of a weaker one.

EMERGENCE OF THE MODERN SCIENCES OF ELECTRICITY AND MAGNETISM

The founder of the modern sciences of electricity and magnetism was William Gilbert, physician to both Elizabeth I and James I of England. Gilbert spent 17 years experimenting with magnetism and, to a lesser extent, electricity. He assembled the results of his experiments and all of the available knowledge on magnetism in the treatise *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure* ("On the Magnet and Magnetic Bodies, and on That Great Magnet the Earth"). As suggested by the title, Gilbert described the Earth as a huge magnet. He introduced the term electric for the force between two objects charged by friction and showed that frictional electricity occurs in many common materials. He also noted one of the primary distinctions between magnetism and electricity: the force between magnetic objects tends to align the objects relative to each other and is affected only slightly by most intervening objects, while the force between electrified objects is primarily a force of attraction or repulsion between the objects and is grossly affected by intervening matter. Gilbert attributed the electrification of a body by friction to the removal of a fluid, or "humour," which then left an "effluvium," or atmosphere, around the body. The language is quaint, but, if the "humour" is renamed "charge" and the "effluvium" renamed "electric field," Gilbert's notions closely approach modern ideas.

Pioneering efforts. During the 17th and early 18th centuries, as better sources of charge were developed, the study of electric effects became increasingly popular. The first machine to generate an electric spark was built in 1663 by Otto von Guericke, a German physicist and engineer. Guericke's electric generator consisted of a sulfur globe mounted on an iron shaft. The globe could be turned with one hand and rubbed with the other. Electrified by friction, the sphere alternately attracted and repulsed light objects from the floor.

Stephen Gray, a British chemist, is credited with discovering that electricity can flow (1729). He found that corks stuck in the ends of glass tubes become electrified when the tubes are rubbed. He also transmitted electricity approximately 150 metres through a hemp thread supported by silk cords and, in another demonstration, sent electricity even farther through metal wire. Gray concluded that electricity flowed everywhere.

From the mid-18th through the early 19th centuries, scientists believed that electricity was composed of fluid. In 1733 Charles François de Cisternay DuFay, a French chemist, announced that electricity consisted of two fluids: "vitreous" (from the Latin for "glass"), or positive, electricity; and "resinous," or negative, electricity. When DuFay electrified a glass rod, it attracted nearby bits of cork. Yet, if the rod touched the pieces of cork, the cork fragments were repelled and also repelled one another. DuFay accounted for this phenomenon by explaining that, in general, matter was neutral because it contained equal quantities of both fluids; if, however, friction separated the fluids in a substance and left it imbalanced, the substance would attract or repel other matter.

Invention of the Leyden jar. In 1745 a cheap and convenient source of electric sparks was invented by Pieter van Musschenbroek, a physicist and mathematician in Leiden, Neth. Later called the Leyden jar, it was the first device that could store large amounts of electric charge. (E. Georg von Kleist, a German cleric, independently developed the idea for such a device, but did not investigate it as thoroughly as did Musschenbroek.) The Leyden jar devised by the latter consisted of a glass vial that was partially filled with water and contained a thick conducting wire capable of storing a substantial amount of charge. One end of this wire protruded through the cork that sealed the opening of the vial. The Leyden jar was charged by bringing this exposed end of the conducting wire into contact with a friction device that generated static electricity.

Within a year after the appearance of Musschenbroek's device, William Watson, an English physician and scientist, constructed a more sophisticated version of the Leyden jar; he coated the inside and outside of the container with metal foil to improve its capacity to store charge. Watson transmitted an electric spark from his device through a wire strung across the River Thames at Westminster Bridge in 1747.

The Leyden jar revolutionized the study of electrostatics. Soon "electricians" were earning their living all over Europe demonstrating electricity with Leyden jars. Typically, they killed birds and animals with electric shock or sent charges through wires over rivers and lakes. In 1746 the abbé Jean-Antoine Nollet, a physicist who popularized science in France, discharged a Leyden jar in front of King Louis XV by sending current through a chain of 180 Royal Guards. In another demonstration, Nollet used wire made of iron to connect a row of Carthusian monks more than a kilometre long; when a Leyden jar was discharged, the white-robed monks reportedly leapt simultaneously into the air.

In the United States, Benjamin Franklin sold his printing house, newspaper, and almanac to spend his time conducting electricity experiments. In 1752 Franklin proved that lightning was an example of electric conduction by flying a silk kite during a thunderstorm. He collected electric charge from a cloud by means of wet twine attached to a key and thence to a Leyden jar. He then used the accumulated charge from the lightning to perform electric experiments. Franklin enunciated the law now known as the conservation of charge (the net sum of the charges within an isolated region is always constant). Like Watson, he disagreed with DuFay's two-fluid theory. Franklin argued that electricity consisted of two states of one fluid, which is present in everything. A substance containing an unusually large amount of the fluid would be "plus," or positively charged. Matter with less than a normal amount of fluid would be "minus," or negatively charged.

Franklin's one-fluid theory

Franklin's one-fluid theory, which dominated the study of electricity for 100 years, is essentially correct because most currents are the result of moving electrons. At the same time, however, fundamental particles have both negative and positive charges and, in this sense, DuFay's two-fluid picture is correct.

Joseph Priestley, an English physicist, summarized all available data on electricity in his book *History and Present*

State of Electricity (1767). He repeated one of Franklin's experiments, in which the latter had dropped small corks into a highly electrified metal container and found that they were neither attracted nor repelled. The lack of any charge on the inside of the container caused Priestley to recall Newton's law that there is no gravitational force on the inside of a hollow sphere. From this, Priestley inferred that the law of force between electric charges must be the same as the law for gravitational force—*i.e.*, that the force between masses diminishes with the inverse square of the distance between the masses. Although they were expressed in qualitative and descriptive terms, Priestley's laws are still valid today. Their mathematics was clarified and developed extensively between 1767 and the mid-19th century as electricity and magnetism became precise, quantitative sciences.

Formulation of the quantitative laws of electrostatics and magnetostatics. Charles-Augustin de Coulomb established electricity as a mathematical science during the latter half of the 18th century. He transformed Priestley's descriptive observations into the basic quantitative laws of electrostatics and magnetostatics. He also developed the mathematical theory of electric force and invented the torsion balance that was to be used in electricity experiments for the next 100 years. Coulomb used the balance to measure the force between magnetic poles and between electric charges at varying distances. In 1785 he announced his quantitative proof that electric and magnetic forces vary, like gravitation, inversely as the square of the distance (see above *General considerations*). Thus, according to Coulomb's law, if the distance between two charged masses is doubled, the electric force between them is reduced to a fourth. (The English physicist Henry Cavendish, as well as John Robison of Scotland, had made quantitative determinations of this principle before Coulomb, but they had not published their work.)

The mathematicians Siméon-Denis Poisson of France and Carl Friedrich Gauss of Germany extended Coulomb's work during the 18th and early 19th centuries. Poisson's equation (published in 1813) and the law of charge conservation contain in two lines virtually all the laws of electrostatics. The theory of magnetostatics, which is the study of steady-state magnetic fields, also was developed from Coulomb's law. Magnetostatics uses the concept of a magnetic potential analogous to the electric potential (*i.e.*, magnetic poles are postulated with properties analogous to electric charges).

Michael Faraday built upon Priestley's work and conducted an experiment that verified quite accurately the inverse square law. Faraday's experiment involving the use of a metal ice pail and a gold-leaf electroscope was the first precise quantitative experiment on electric charge. In Faraday's time, the gold-leaf electroscope was used to indicate the electric state of a body. This type of apparatus consists of two thin leaves of gold hanging from an insulated metal rod that is mounted inside a metal box. When the rod is charged, the leaves repel each other and the deflection indicates the size of the charge. Faraday began his experiment by charging a metal ball suspended on an insulating silk thread. He then connected the gold-leaf electroscope to a metal ice pail resting on an insulating block and lowered the charged ball into the pail. The electroscope reading increased as the ball was lowered into the pail and reached a steady value once the ball was within the pail. When the ball was withdrawn without touching the pail, the electroscope reading fell to zero. Yet, when the ball touched the bottom of the pail, the reading remained at its steady value. On removal, the ball was found to be completely discharged. Faraday concluded that the electric charge produced on the outside of the pail, when the ball was inside but not in contact with it, was exactly equal to the initial charge on the ball. He then inserted into the pail other objects, such as a set of concentric pails separated from one another with various insulating materials like sulfur. In each case, the electroscope reading was the same once the ball was completely within the pail. From this, Faraday concluded that the total charge of the system was an invariable quantity equal

Faraday's verification of the inverse square law

By courtesy of *Scientific American*, December 1988



Figure 49: *Widespread use of electricity in the 19th century.*
The study and use of electricity affected nearly every area of 19th-century life, even grand opera. In 1888 two singers in a performance of Charles Gounod's *Faust* staged a spectacular duel scene by forming an electric circuit. Their swords were connected to the poles of a battery under the stage floor via wires hidden beneath their costumes, copper nails in their shoes, and metal plates on the stage floor. Each time the swords touched, they sparkled and crackled like lightning.

to the initial charge of the ball. The present-day belief that conservation is a fundamental property of charge rests not only on the experiments of Franklin and Faraday but also on its complete agreement with all observations in electric engineering, quantum electrodynamics, and experimental electricity. With Faraday's work, the theory of electrostatics was complete.

FOUNDATIONS OF ELECTROCHEMISTRY AND ELECTRODYNAMICS

Development of the battery. The invention of the battery in 1800 made possible for the first time major advances in the theories of electric current and electrochemistry. Both science and technology developed rapidly as a direct result, leading some to call the 19th century the age of electricity.

The development of the battery was the accidental result of biological experiments conducted by Luigi Galvani. Galvani, a professor of anatomy at the Bologna Academy of Science, was interested in electricity in fish and other animals. One day he noticed that electric sparks from an electrostatic machine caused muscular contractions in a dissected frog that lay nearby. At first, Galvani assumed that the phenomenon was the result of atmospheric electricity because similar effects could be observed during lightning storms. Later, he discovered that whenever a piece of metal connected the muscle and nerve of the frog, the muscle contracted. Although Galvani realized that some metals appeared to be more effective than others in producing this effect, he concluded incorrectly that the metal was transporting a fluid, which he identified with animal electricity, from the nerve to the muscle. Galvani's observations, published in 1791, aroused considerable controversy and speculation.

Alessandro Volta, a physicist at the nearby University of Pavia, had been studying how electricity stimulates the senses of touch, taste, and sight. When Volta put a metal coin on top of his tongue and another coin of a different metal under his tongue and connected their surfaces with a wire, the coins tasted salty. Like Galvani, Volta assumed that he was working with animal electricity until 1796 when he discovered that he could also produce a current when he substituted a piece of cardboard soaked in brine for his tongue. Volta correctly conjectured that the effect was caused by the contact between metal and a moist body. Around 1800 he constructed what is now known as a voltaic pile consisting of layers of silver, moist cardboard, and zinc, repeated in that order, beginning and ending with a different metal. When he joined the silver and the zinc with a wire, electricity flowed continuously through the wire. Volta confirmed that the effects of his pile were equivalent in every way to those of static electricity. Within 20 years, galvanism, as electricity produced by a chemical reaction was then called, became unequivocally linked to static electricity. More important, Volta's invention provided the first source of continuous electric current. This rudimentary form of battery produced a smaller voltage than the Leyden jar, but it was easier to use because it could supply a steady current and did not have to be recharged.

Voltaic pile

The controversy between Galvani, who mistakenly thought that electricity originated in the animal's nerve, and Volta, who realized that it came from the metal, divided scientists into two camps. Galvani was supported by Alexander von Humboldt in Germany, while Volta was backed by Coulomb and other French physicists.

Within six weeks of Volta's report, two English scientists, William Nicholson and Anthony Carlisle, used a chemical battery to discover electrolysis (the process in which an electric current produces a chemical reaction) and initiate the science of electrochemistry. In their experiment the two employed a voltaic pile to liberate hydrogen and oxygen from water. They attached each end of the pile to brass wires and placed the opposite ends of the wires into salt water. The salt made the water a conductor. Hydrogen gas accumulated at the end of one wire; the end of the other wire was oxidized. Nicholson and Carlisle discovered that the amount of hydrogen and oxygen set free by the current was proportional to the amount of current used.

Discovery of electrolysis

By 1809 the English chemist Humphry Davy had used a stronger battery to free for the first time several very active metals—sodium, potassium, calcium, strontium, barium, and magnesium—from their liquid compounds. Faraday, who was Davy's assistant at the time, studied electrolysis quantitatively and showed that the amount of energy needed to separate a gram of a substance from its compound is closely related to the atomic weight of the substance. Electrolysis became a method of measuring electric current; and the quantity of charge that releases a gram atomic weight of a simple element is now called a faraday in his honour.

Once scientists were able to produce currents with a battery, they could study the flow of electricity quantitatively. Because of the battery, the German physicist Georg Simon Ohm was able experimentally in 1827 to quantify precisely a problem that Cavendish could only investigate qualitatively some 50 years earlier—namely, the ability of a material to conduct electricity. The result of this work—Ohm's law—explains how the resistance to the flow of charge depends on the type of conductor and on its length and diameter. According to Ohm's formulation, the current flow through a conductor is directly proportional to the potential difference, or voltage, and inversely proportional to the resistance—that is, $i = V/R$. Thus, doubling the length of an electric wire doubles its resistance, while doubling the cross-sectional area of the wire reduces the resistance by a half. Ohm's law is probably the most widely used equation in electric design.

Experimental and theoretical studies of electromagnetic phenomena. One of the great turning points in the development of the physical sciences was Hans Christian Ørsted's announcement in 1820 that electric currents produce magnetic effects. (Ørsted made his discovery while lecturing to a class of physics students. He placed by chance a wire carrying current near a compass needle and was surprised to see the needle swing at right angles to the wire.) Ørsted's fortuitous discovery proved that electricity and magnetism are linked. His finding, together with Faraday's subsequent discovery that a changing magnetic field produces an electric current in a nearby circuit, formed the basis of both James Clerk Maxwell's unified theory of electromagnetism and most of modern electrotechnology.

Verification of the link between electricity and magnetism

Once Ørsted's experiment had revealed that electric currents have magnetic effects, scientists realized that there must be magnetic forces between the currents. They began studying the forces immediately. A French physicist, François Arago, observed in 1820 that an electric current will orient unmagnetized iron filings in a circle around the wire. That same year, another French physicist, André-Marie Ampère, developed Ørsted's observations in quantitative terms. Ampère showed that two parallel wires carrying electric currents attract and repel each other like magnets. If the currents flow in the same direction, the wires attract each other; if they flow in opposite directions, the wires repel each other. From this experiment, Ampère was able to express the right-hand rule for the direction of the force on a current in a magnetic field. He also established experimentally and quantitatively the laws of magnetic force between electric currents. He suggested that internal electric currents are responsible for permanent magnets and for highly magnetizable materials like iron. With Arago, he demonstrated that steel needles become more strongly magnetic inside a coil carrying an electric current. Experiments on small coils showed that, at large distances, the forces between two such coils are similar to those between two small bar magnets and, moreover, that one coil can be replaced by a bar magnet of suitable size without changing the forces. The magnetic moment of this equivalent magnet was determined by the dimensions of the coil, its number of turns, and the current flowing around it.

William Sturgeon of England and Joseph Henry of the United States used Ørsted's discovery to develop electromagnets during the 1820s. Sturgeon wrapped 18 turns of bare copper wire around a U-shaped iron bar. When he turned on the current, the bar became an electromagnet capable of lifting 20 times its weight. When the current was turned off, the bar was no longer magnetized. Henry

repeated Sturgeon's work in 1829, using insulated wire to prevent short-circuiting. Using hundreds of turns, Henry created an electromagnet that could lift more than one ton of iron.

Ørsted's experiment showing that electricity could produce magnetic effects raised the opposite question as well: Could magnetism induce an electric current in another circuit? The French physicist Augustin-Jean Fresnel argued that since a steel bar inside a metallic helix can be magnetized by passing a current through the helix, the bar magnet in turn should create a current in an enveloping helix. In the following decade many ingenious experiments were devised, but the expectation that a steady current would be induced in a coil near the magnet resulted in experimenters either accidentally missing or not appreciating any transient electric effects caused by the magnet.

Faraday's discovery of electric induction

Faraday, the greatest experimentalist in electricity and magnetism of the 19th century and one of the greatest experimental physicists of all time, worked on and off for 10 years trying to prove that a magnet could induce electricity. In 1831 he finally succeeded by using two coils of wire wound around opposite sides of a ring of soft iron (Figure 50). The first coil was attached to a battery; when a current passed through the coil, the iron ring became magnetized. A wire from the second coil was extended to a compass needle a metre away, far enough so that it was not affected directly by any current in the first circuit. When the first circuit was turned on, Faraday observed a momentary deflection of the compass needle and its immediate return to its original position. When the primary current was switched off, a similar deflection of the compass needle occurred but in the opposite direction. Building on this observation in other experiments, Faraday showed that changes in the magnetic field around the first coil are responsible for inducing the current in the second coil. He also demonstrated that an electric current can be induced by moving a magnet, by turning an electromagnet on and off, and even by moving an electric wire in the Earth's magnetic field. Within a few months, Faraday built the first, albeit primitive, electric generator.

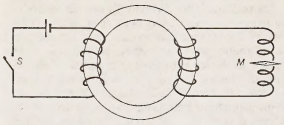

Figure 50: Faraday's magnetic induction experiment. When the switch S is closed in the primary circuit, a momentary current flows in the secondary circuit, giving a transient deflection of the compass needle M.

Henry had discovered electric induction quite independently in 1830, but his results were not published until after he had received news of Faraday's 1831 work, nor did he develop the discovery as fully as Faraday. In his paper of July 1832, Henry reported and correctly interpreted self-induction. He had produced large electric arcs from a long helical conductor when it was disconnected from a battery. When he had opened the circuit, the rapid decrease in the current had caused a large voltage between the battery terminal and the wire. As the wire lead was pulled away from the battery, the current continued to flow for a short time in the form of a bright arc between the battery terminal and the wire.

Faraday's thinking was permeated by the concept of electric and magnetic lines of force. He visualized that magnets, electric charges, and electric currents produce lines of force. When he placed a thin card covered with iron filings on a magnet, he could see the filings form chains from one end of the magnet to the other. He believed that these lines showed the directions of the forces and that electric current would have the same lines of force. The tension they build explains the attraction and repulsion of magnets and electric charges. Faraday had visualized magnetic curves as early as 1831 while working on his induction experiments; he wrote in his notes, "By magnetic curves I mean lines of magnetic forces which would be depicted by iron filings." Faraday opposed the prevailing idea that induction occurred "at a distance"; instead, he held that induction occurs along curved lines of force because of the action of contiguous particles. Later, he explained that electricity and magnetism are transmitted through a medium that is the site of electric or magnetic "fields," which make all substances magnetic to some extent.

Faraday was not the only researcher laying the groundwork for a synthesis between electricity, magnetism, and other areas of physics. On the continent of Europe, primarily in Germany, scientists were making mathematical connections between electricity, magnetism, and optics. The work of the physicists Franz Ernst Neumann, Wilhelm Eduard Weber, and H.F.E. Lenz belongs to this period. At the same time, Helmholtz and the English physicists William Thomson (later Lord Kelvin) and James Prescott Joule were clarifying the relationship between electricity and other forms of energy. Joule investigated the quantitative relationship between electric currents and heat during the 1840s and formulated the theory of the heating effects that accompany the flow of electricity in conductors. Helmholtz, Thomson, Henry, Gustav Kirchhoff, and Sir George Gabriel Stokes also extended the theory of the conduction and propagation of electric effects in conductors. In 1856 Weber and his German colleague, Rudolf Kohlrausch, determined the ratio of electric and magnetic units and found that it has the same dimensions as light and that it is almost exactly equal to its velocity. In 1857 Kirchhoff used this finding to demonstrate that electric disturbances propagate on a highly conductive wire with the speed of light.

Formulation of the classical theory of electromagnetism

The final steps in synthesizing electricity and magnetism into one coherent theory were made by Maxwell. He was deeply influenced by Faraday's work, having begun his study of the phenomena by translating Faraday's experimental findings into mathematics. (Faraday was self-taught and had never mastered mathematics.) In 1856 Maxwell developed the theory that the energy of the electromagnetic field is in the space around the conductors as well as in the conductors themselves. By 1864 he had formulated his own electromagnetic theory of light, predicting that both light and radio waves are electric and magnetic phenomena. While Faraday had discovered that changes in magnetic fields produce electric fields, Maxwell added the converse: changes in electric fields produce magnetic fields even in the absence of electric currents. Maxwell predicted that electromagnetic disturbances traveling through empty space have electric and magnetic fields at right angles to each other and that both fields are perpendicular to the direction of the wave. He concluded that the waves move at a uniform speed equal to the speed of light and that light is one form of electromagnetic wave. Their elegance notwithstanding, Maxwell's radical ideas were accepted by few outside England until 1886, when the German physicist Heinrich Hertz verified the existence of electromagnetic waves traveling at the speed of light; the waves he discovered are known now as radio waves.

Maxwell's four field equations (see above) represent the pinnacle of classical electromagnetic theory. Subsequent developments in the theory have been concerned either with the relationship between electromagnetism and the atomic structure of matter or with the practical and theoretical consequences of Maxwell's equations. His formulation has withstood the revolutions of relativity and quantum mechanics. His equations are appropriate for distances as small as 10^{-10} centimetres—100 times smaller than the size of an atom. The fusion of electromagnetic theory and quantum theory, known as quantum electrodynamics, is required only for smaller distances.

While the mainstream of theoretical activity concerning electric and magnetic phenomena during the 19th century was devoted to showing how they are interrelated, some scientists made use of them to discover new properties of materials and heat. Weber developed Ampère's suggestion that there are internal circulating currents of molecular size in metals. He explained how a substance loses its magnetic properties when the molecular magnets point in

random directions. Under the action of an external force, they may turn to point in the direction of the force; when all point in this direction, the maximum possible degree of magnetization is reached, a phenomenon known as magnetic saturation. In 1895 Pierre Curie of France discovered that a ferromagnetic substance has a specific temperature above which it ceases to be magnetic. Finally, superconductivity was discovered in 1900 by the German physicist Heike Kammerlingh-Onnes. In superconductivity electric conductors lose all resistance at very low temperatures.

Discovery of the electron and its ramifications. Although little of major importance was added to electromagnetic theory in the 19th century after Maxwell, the discovery of the electron in 1898 opened up an entirely new area of study: the nature of electric charge and of matter itself. The discovery of the electron grew out of studies of electric currents in vacuum tubes. Heinrich Geissler, a glassblower who assisted the German physicist Julius Plücker, improved the vacuum tube in 1854. Four years later, Plücker sealed two electrodes inside the tube, evacuated the air, and forced electric currents between the electrodes; he attributed the green glow that appeared on the wall of the tube to rays emanating from the cathode. From then until the end of the century, the properties of cathode-ray discharges were studied intensively. The work of the English physicist Sir William Crookes in 1879 indicated that the luminescence was a property of the electric current itself. Crookes concluded that the rays were composed of electrified charged particles. In 1898 another English physicist, Sir J.J. Thomson, identified a cathode ray as a stream of negatively charged particles, each having a mass $^1/_{1836}$ smaller than that of a hydrogen ion. Thomson's discovery established the particulate nature of charge; his particles were later dubbed electrons.

Studies of currents in vacuum tubes

Following the discovery of the electron, electromagnetic theory became an integral part of the theories of the atomic, subatomic, and subnuclear structure of matter. This shift in focus occurred as the result of an impasse between electromagnetic theory and statistical mechanics over attempts to understand radiation from hot bodies. Thermal radiation had been investigated in Germany by the physicist Wilhelm Wien between 1890 and 1900. Wien had virtually exhausted the resources of thermodynamics in dealing with this problem. Two British scientists, Lord Rayleigh (John William Strutt) and Sir James Hopwood Jeans, had by 1900 applied the newly developed science of statistical mechanics to the same problem. They obtained results that, though in agreement with Wien's thermodynamic conclusions (as distinct from his speculative extensions of thermodynamics), only partially agreed with experimental observations. The German physicist Max Planck attempted to combine the statistical approach with a thermodynamic approach. By concentrating on the necessity of fitting together the experimental data, he was led to the formulation of an empirical law that satisfied Wien's thermodynamic criteria and accommodated the experimental data. When Planck interpreted this law in terms of Rayleigh's statistical concepts, he concluded that radiation of frequency ν exists only in quanta of energy. Planck's result, including the introduction of the new universal constant h in 1900, marked the foundation of quantum mechanics and initiated a profound change in physical theory (see ATOMS: *Bohr's shell model*).

By 1900 it was apparent that Thomson's electrons were a universal constituent of matter and, thus, that matter is essentially electric in nature. As a result, in the early years of the 20th century, many physicists attempted to construct theories of the electromagnetic properties of metals, insulators, and magnetic materials in terms of electrons. In 1909 the Dutch physicist Hendrik Antoon Lorentz succeeded in doing so in *The Theory of Electrons and Its Applications to the Phenomena of Light and Radiant Heat;* his work has since been modified by quantum theory.

Special theory of relativity. The other major conceptual advance in electromagnetic theory was the special theory of relativity. In Maxwell's time, a mechanistic view of the universe held sway. Sound was interpreted as an undulatory motion of the air, while light and other electromagnetic waves were regarded as undulatory motions of an intangible medium called ether. The question arose as to whether the velocity of light measured by an observer moving relative to ether would be affected by his motion. Albert Abraham Michelson and Edward W. Morley of the United States had demonstrated in 1887 that light in a vacuum on Earth travels at a constant speed which is independent of the direction of the light relative to the direction of the Earth's motion through the ether. Lorentz and Henri Poincaré, a French physicist, showed between 1900 and 1904 that the conclusions of Michelson and Morley were consistent with Maxwell's equations. On this basis, Lorentz and Poincaré developed a theory of relativity in which the absolute motion of a body relative to a hypothetical ether is no longer significant. Poincaré named the theory the principle of relativity in a lecture at the St. Louis Exposition in September 1904. Planck gave the first formulation of relativistic dynamics two years later. The most general formulation of the special theory of relativity, however, was put forth by Einstein in 1905, and the theory of relativity is usually associated with his name. Einstein postulated that the speed of light is a constant, independent of the motion of the source of the light, and showed how the Newtonian laws of mechanics would have to be modified. While Maxwell had synthesized electricity and magnetism into one theory, he had regarded them as essentially two interdependent phenomena; Einstein showed that they are two aspects of the same phenomenon.

Lorentz's and Poincaré's principle of relativity

Maxwell's equations, the special theory of relativity, the discovery of the electronic structure of matter, and the formulation of quantum mechanics all occurred before 1930. The quantum electrodynamics theory, developed between 1945 and 1955, subsequently resolved some minute discrepancies in the calculations of certain atomic properties. For example, the accuracy with which it is now possible to calculate one of the numbers describing the magnetic moment of the electron is comparable to measuring the distance between New York City and Los Angeles to within the thickness of a human hair. As a result, quantum electrodynamics is the most complete and precise theory of any physical phenomenon. The remarkable correspondence between theory and observation makes it unique among human endeavours.

DEVELOPMENT OF ELECTROMAGNETIC TECHNOLOGY

Electromagnetic technology began with Faraday's discovery of induction in 1831 (see above). His demonstration that a changing magnetic field induces an electric current in a nearby circuit showed that mechanical energy can be converted to electric energy. It provided the foundation for electric power generation, leading directly to the invention of the dynamo and the electric motor. Faraday's finding also proved crucial for lighting and heating systems.

The early electric industry was dominated by the problem of generating electricity on a large scale. Within a year of Faraday's discovery, a small hand-turned generator in which a magnet revolved around coils was demonstrated in Paris. In 1833 there appeared an English model that featured the modern arrangement of rotating the coils in the field of a fixed magnet. By 1850 generators were manufactured commercially in several countries. Permanent magnets were used to produce the magnetic field in generators until the principle of the self-excited generator was discovered in 1866. (A self-excited generator has stronger magnetic fields because it uses electromagnets powered by the generator itself.) In 1870 Zénobe Théophile Gramme, a Belgian manufacturer, built the first practical generator capable of producing a continuous current. It was soon found that the magnetic field is more effective if the coil windings are embedded in slots in the rotating iron armature. The slotted armature, still in use today, was invented in 1880 by the Swedish engineer Jonas Wenström. Faraday's 1831 discovery of the principle of the AC transformer was not put to practical use until the late 1880s when the heated debate over the merits of direct-current and alternating-current systems for power transmission was settled in favour of the latter.

Self-excited generator

At first, the only serious consideration for electric power was arc lighting, in which a brilliant light is emitted by

an electric spark between two electrodes. The arc lamp was too powerful for domestic use, however, and so it was limited to large installations like lighthouses, train stations, and department stores. Commercial development of an incandescent filament lamp, first invented in the 1840s, was delayed until a filament could be made that would heat to incandescence without melting and until a satisfactory vacuum tube could be built. The mercury pump, invented in 1865, provided an adequate vacuum, and a satisfactory carbon filament was developed independently by the English physicist Sir Joseph Wilson Swan and the American inventor Thomas A. Edison during the late 1870s. By 1880 both had applied for patents for their incandescent lamps, and the ensuing litigation between the two men was resolved by the formation of a joint company in 1883. Thanks to the incandescent lamp, electric lighting became an accepted part of urban life by 1900. Since then, the tungsten filament lamp, introduced during the early 1900s, has become the principal form of electric lamp, though more efficient fluorescent gas discharge lamps have found widespread use as well.

Electricity took on a new importance with the development of the electric motor. This machine, which converts electric energy to mechanical energy, has become an integral component of a wide assortment of devices ranging from kitchen appliances and office equipment to industrial robots and rapid-transit vehicles. Although the principle of the electric motor was devised by Faraday in 1821, no commercially significant unit was produced until 1873. In fact, the first important AC motor, built by the Serbian-American inventor Nikola Tesla, was not demonstrated in the United States until 1888. Tesla began producing his motors in association with the Westinghouse Electric Company a few years after DC motors had been installed in trains in Germany and Ireland. By the end of the 19th century, the electric motor had taken a recognizably modern form. Subsequent improvements have rarely involved radically new ideas; however, the introduction of better designs and new bearing, armature, magnetic, and contact materials has resulted in the manufacture of smaller, cheaper, and more efficient and reliable motors.

The modern communications industry is among the most spectacular products of electricity. Telegraph systems using wires and simple electrochemical or electromechanical receivers proliferated in western Europe and the United States during the 1840s. An operable cable was installed under the English Channel in 1865, and a pair of transatlantic cables were successfully laid a year later. By 1872 almost all of the major cities of the world were linked by telegraph.

Alexander Graham Bell patented the first practical telephone in the United States in 1876, and the first public telephone services were operating within a few years. In 1895 the British physicist Sir Ernest Rutherford advanced Hertz's scientific investigations of radio waves and transmitted radio signals for more than one kilometre. Guglielmo Marconi, an Italian physicist and inventor, established wireless communications across the Atlantic employing radio waves of approximately 300- to 3,000-metre wavelength in 1901. Broadcast radio transmissions were established during the 1920s.

Transmission of radio signals

Telephone transmissions by radio waves, the electric recording and reproduction of sound, and television were made possible by the development of the triode tube. This three-electrode tube, invented by the American engineer Lee De Forest, permitted for the first time the amplification of electric signals. Known as the Audion, this device played a pivotal role in the early development of the electronics industry.

The first telephone transmission via radio signals was made from Arlington, Va., to the Eiffel Tower in Paris in 1915; and a commercial radio telephone service between New York City and London was begun in 1927. Besides such efforts, most of the major developmental work of this period was tied to the radio and phonograph entertainment industries and the sound film industry. Rapid progress was made toward transmitting moving pictures, especially in Great Britain; just before World War II, the British Broadcasting Corporation inaugurated the first public television service. Today, many regions of the electromagnetic spectrum are used for communications, including microwaves in the frequency range of approximately 7×10^9 hertz for satellite communication links and infrared light at a frequency of about 3×10^{14} hertz for optical fibre communications systems.

Until 1939 the electronics industry was almost exclusively concerned with communications and broadcast entertainment. Scientists and engineers in Britain, Germany, France, and the United States did initiate research on radar systems capable of aircraft detection and antiaircraft fire-control during the 1930s, however, and this marked the beginning of a new direction for electronics. During World War II and after, the electronics industry made strides paralleled only by those of the chemical industry. Television became commonplace; and a broad array of new devices and systems, most notably the electronic digital computer, emerged.

The electronic revolution of the last half of the 20th century has been made possible in large part by the invention of the transistor (1947) and such subsequent developments as the integrated circuit. (For detailed coverage of these and other major advances, see ELECTRONICS.) This miniaturization and integration of circuit elements has led to a remarkable diminution in the size and cost of electronic equipment and an equally impressive increase in its reliability. (F.N.H.R./E.Ka./S.McG.)

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Electromagnetic Radiation

In terms of classical theory, electromagnetic radiation is the flow of energy through space at the universal speed of light in the form of electric and magnetic fields that make up an electromagnetic wave. In such a wave, time-varying electric and magnetic fields are mutually linked with each other at right angles and perpendicular to the direction of motion. An electromagnetic wave is characterized by its intensity and the frequency ν of the time variation of the electric and magnetic fields.

In terms of the modern quantum theory, electromagnetic radiation is the flow of photons (also called light quanta) through space. Photons are packets of energy $h\nu$ that always move with the universal speed of light. The symbol h is Planck's constant, while the value of ν is the same as that of the frequency of the electromagnetic wave of classical theory. Photons having the same energy $h\nu$ are all alike, and their number density corresponds to the intensity of the radiation. Electromagnetic radiation exhibits a multitude of phenomena as it interacts with charged particles in atoms, molecules, and larger objects of matter. These phenomena as well as the ways in which electromagnetic radiation is created and observed, the manner in which such radiation occurs in nature, and its technological uses depend on its frequency ν. The spectrum of frequencies of electromagnetic radiation extends from very low values over the range of radio waves, television waves, and microwaves to visible light and beyond to the substantially higher values of ultraviolet light, X rays, and gamma rays.

The basic properties and behaviour of electromagnetic radiation are discussed in this article, as are its various forms, including their sources, distinguishing characteristics, and practical applications. The article also traces the development of both the classical and quantum theories of radiation.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 111, 112, 127, 128, and 131, and the *Index*.

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General considerations

OCCURRENCE AND IMPORTANCE

Close to 0.01 percent of the mass/energy of the entire universe occurs in the form of electromagnetic radiation. All human life is immersed in it and modern communications technology and medical services are particularly dependent on one or another of its forms. In fact, all living things on Earth depend on the electromagnetic radiation received from the Sun and on the transformation of solar energy by photosynthesis into plant life or by biosynthesis into zooplankton, the basic step in the food chain in oceans. The eyes of many animals, including those of humans, are adapted to be sensitive to and hence to see the most abundant part of the Sun's electromagnetic radiation—namely, light, which comprises the visible portion of its wide range of frequencies. Green plants also have high sensitivity to the maximum intensity of solar electromagnetic radiation, which is absorbed by a substance called chlorophyll that is essential for plant growth via photosynthesis.

Importance to life

Practically all the fuels that modern society uses—gas, oil, and coal—are stored forms of energy received from the Sun as electromagnetic radiation millions of years ago. Only the energy from nuclear reactors does not originate from the Sun.

Everyday life is pervaded by man-made electromagnetic radiation: food is heated in microwave ovens, airplanes are guided by radar waves, television sets receive electromagnetic waves transmitted by broadcasting stations, and infrared waves from heaters provide warmth. Infrared waves also are given off and received by automatic self-focusing cameras that electronically measure and set the correct distance to the object to be photographed. As soon as the Sun sets, incandescent or fluorescent lights are turned on to provide artificial illumination, and cities glow brightly with the colourful fluorescent and neon lamps of advertisement signs. Familiar too is ultraviolet radiation, which the eyes cannot see but whose effect is felt as pain from sunburn. Ultraviolet light represents a kind of electromagnetic radiation that can be harmful to life. Such is also true of X rays, which are important in medicine as they allow physicians to observe the inner parts of the body but exposure to which should be kept to a minimum. Less familiar are gamma rays, which come from nuclear reactions and radioactive decay and are part of the harmful high-energy radiation of radioactive materials and nuclear weapons.

THE ELECTROMAGNETIC SPECTRUM

The brief account of familiar phenomena given above surveyed electromagnetic radiation from small frequencies ν (long wave radios) to exceedingly high values of ν (gamma rays). Going from the ν values of radio waves to those of visible light is like comparing the thickness of this page with the distance of the Earth from the Sun, which represents an increase by a factor of a million billion. Similarly, going from the ν values of visible light to the very much larger ones of gamma rays represents another increase in frequency by a factor of a million billion. This extremely large range of ν values, called the electromagnetic spec-

Vast range of frequencies

trum, is shown in Figure 1, together with the common names used for its various parts, or regions.

The number ν is shared by both the classical and the modern interpretation of electromagnetic radiation. In classical language, ν is the frequency of the temporal changes in an electromagnetic wave. The frequency of a wave is related to its speed c and wavelength λ in the following way. If 10 complete waves pass by in one second, one observes 10 wriggles, and one says that the frequency of such a wave is $\nu = 10$ cycles per second (10 hertz [Hz]). If the wavelength of the wave is, say, $\lambda = 3$ centimetres, then it is clear that a wave train 30 centimetres long has passed in that one second to produce the 10 wriggles that were observed. Thus, the speed of the wave is 30 centimetres per second, and one notes that in general the speed is $c = \lambda\nu$. The speed of electromagnetic radiation of all kinds is the same universal constant that is defined to be exactly $c = 299{,}792{,}458$ metres per second (186,282 miles per second). The wavelengths of the classical electromagnetic waves in free space calculated from $c = \lambda\nu$ are also shown on the spectrum in Figure 1, as is the energy $h\nu$ of modern-day photons. One commonly uses as the unit of energy electron volt (eV), which is the energy that can be given to an electron by a one-volt battery. It is clear that the range of wavelengths λ and of photon energies $h\nu$ are equally as large as the spectrum of ν values.

Because the wavelengths and energy quanta $h\nu$ of electromagnetic radiation of the various parts of the spectrum are so different in magnitude, the sources of the radiations, the interactions with matter, and the detectors employed are correspondingly different. This is why the same electromagnetic radiation is called by different names in various regions of the spectrum.

In spite of these obvious differences of scale, all forms of electromagnetic radiation obey certain general rules that are well understood and that allow one to calculate with very high precision their properties and interactions with charged particles in atoms, molecules, and large objects.

Electric and magnetic fields

Electromagnetic radiation is, classically speaking, a wave of electric and magnetic fields propagating at the speed of light c through empty space. In this wave the electric and magnetic fields change their magnitude and direction each second. This rate of change is the frequency ν measured in cycles per second—namely, in hertz. The electric and magnetic fields are always perpendicular to one another and at right angles to the direction of propagation, as shown in Figure 2. There is as much energy carried by the electric component of the wave as by the magnetic component, and the energy is proportional to the square of the field strength.

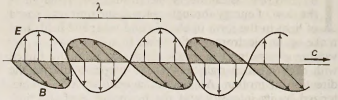

Figure 2: Radiation fields in which vectors *E* and *B* are perpendicular to each other and to the direction of propagation (see text).

GENERATION OF ELECTROMAGNETIC RADIATION

Electromagnetic radiation is produced whenever a charged particle, such as an electron, changes its velocity—*i.e.*, whenever it is accelerated or decelerated. The energy of the electromagnetic radiation thus produced comes from the charged particle and is therefore lost by it. A common example of this phenomenon is the oscillating charge or current in a radio antenna. The antenna of a radio transmitter is part of an electric resonance circuit in which the charge is made to oscillate at a desired frequency. An electromagnetic wave so generated can be received by a similar antenna connected to an oscillating electric circuit in the tuner that is tuned to that same frequency. The electromagnetic wave in turn produces an oscillating motion of charge in the receiving antenna. In general, one can say that any system which emits electromagnetic radiation of a given frequency can absorb radiation of the same frequency.

Such man-made transmitters and receivers become smaller with decreasing wavelength of the electromagnetic wave and prove impractical in the millimetre range. At even shorter wavelengths down to the wavelengths of X rays, which are one million times smaller, the oscillating charges arise from moving charges in molecules and atoms.

Systems or processes that generate electromagnetic radiation

One may classify the generation of electromagnetic radiation into two categories: (1) systems or processes that produce radiation covering a broad continuous spectrum of frequencies and (2) those that emit (and absorb) radiation of discrete frequencies that are characteristic of particular systems. The Sun with its continuous spectrum is an example of the first, while a radio transmitter tuned to one frequency exemplifies the second category.

Continuous spectra of electromagnetic radiation. Such spectra are emitted by any warm substance. Heat is the irregular motion of electrons, atoms, and molecules; the higher the temperature, the more rapid is the motion. Since electrons are much lighter than atoms, irregular thermal motion produces irregular oscillatory charge motion, which reflects a continuous spectrum of frequencies. Each oscillation at a particular frequency can be considered a tiny "antenna" that emits and receives electromagnetic radiation. As a piece of iron is heated to increasingly high temperatures, it first glows red, then yellow, and finally white. In short, all the colours of the visible spectrum are represented. Even before the iron begins to glow red, one can feel the emission of infrared waves by the heat sensation on the skin. A white-hot piece of iron also emits ultraviolet radiation, which can be detected by a photographic film.

Not all materials heated to the same temperature emit the same amount and spectral distribution of electromagnetic waves. For example, a piece of glass heated next to iron looks nearly colourless, but it feels hotter to the skin (it emits more infrared rays) than does the iron. This observation illustrates the rule of reciprocity: a body radiates strongly at those frequencies that it is able to absorb, because for both processes it needs the tiny antennas of that range of frequencies. Glass is transparent in the visible range of light because it lacks possible electronic absorption at these particular frequencies. As a consequence,

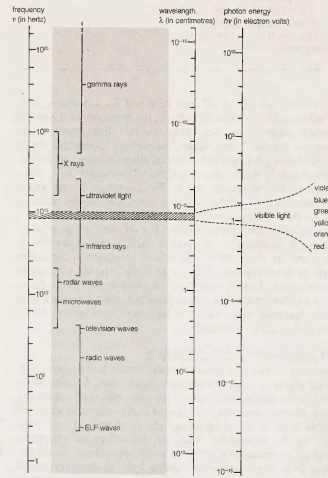

Figure 1: *Electromagnetic spectrum.*
The small visible range (shaded) is shown enlarged at the right.

glass cannot glow red because it cannot absorb red. On the other hand, glass is a better emitter/absorber in the infrared than iron or any other metal that strongly reflects such lower frequency electromagnetic waves. This selective emissivity and absorptivity is important for understanding the greenhouse effect (see below *The greenhouse effect of the atmosphere*) and many other phenomena in nature. The tungsten filament of a light bulb has a temperature of 2,500 K (4,040° F) and emits large amounts of visible light but relatively little infrared because metals, as mentioned above, have small emissivities in the infrared range. This is of course fortunate, since one wants light from a light bulb but not much heat. The light emitted by a candle originates from very hot carbon soot particles in the flame, which strongly absorb and thus emit visible light. By contrast, the gas flame of a kitchen range is pale, even though it is hotter than a candle flame, because of the absence of soot. Light from the stars originates from the high temperature of the gases at their surface. A wide spectrum of radiation is emitted from the Sun's surface, the temperature of which is about 6,000 K. The radiation output is 60 million watts for every square metre of solar surface, which is equivalent to the amount produced by an average-size commercial power-generating station that can supply electric power for about 30,000 households.

The spectral composition of a heated body depends on the materials of which the body consists. That is not the case for an ideal radiator or absorber. Such an ideal object absorbs and thus emits radiation of all frequencies equally and fully. A radiator/absorber of this kind is called a blackbody, and its radiation spectrum is referred to as blackbody radiation, which depends on only one parameter, its temperature. Scientists devise and study such ideal objects because their properties can be known exactly. This information can then be used to determine and understand why real objects, such as a piece of iron or glass, a cloud, or a star, behave differently.

Blackbody radiation

A good approximation of a blackbody is a piece of coal or, better yet, a cavity in a piece of coal that is visible through a small opening. There is one property of blackbody radiation which is familiar to everyone but which is actually quite mysterious. As the piece of coal is heated to higher and higher temperatures, one first observes a dull red glow, followed by a change in colour to bright red; as the temperature is increased further, the colour changes to yellow and finally to white. White is not itself a colour but rather the visual effect of the combination of all primary colours. The fact that white glow is observed at high temperatures means that the colour blue has been added to the ones observed at lower temperatures. This colour change with temperature is mysterious because one would expect, as the energy (or temperature) is increased, just more of the same and not something entirely different. For example, as one increases the power of a radio amplifier, one hears the music louder but not at a higher pitch.

The change in colour or frequency distribution of the electromagnetic radiation coming from heated bodies at different temperatures remained an enigma for centuries. The solution of this mystery by the German physicist Max Planck initiated the era of modern physics at the beginning of the 20th century. He explained the phenomenon by proposing that the tiny antennas in the heated body are quantized, meaning that they can emit electromagnetic radiation only in finite energy quanta of size $h\nu$. The universal constant h is called Planck's constant in his honour. For blue light $h\nu = 3$ eV, whereas $h\nu = 1.8$ eV for red light. Since high-frequency antennas of vibrating charges in solids have to emit larger energy quanta $h\nu$ than lower-frequency antennas, they can only do so when the temperature, or the thermal atomic motion, becomes high enough. Hence, the average pitch, or peak frequency, of blackbody electromagnetic radiation increases with temperature.

Antennas of vibrating changes

The many tiny antennas in a heated chunk of material are, as noted above, to be identified with the accelerating and decelerating charges in the heat motion of the atoms of the material. There are other sources of continuous spectra of electromagnetic radiation that are not associated with heat but still come from accelerated or decelerated charges. X rays are, for example, produced by abruptly stopping rapidly moving electrons. This deceleration of the charges produces bremsstrahlung ("braking radiation"). In an X-ray tube, electrons moving with an energy of $E_{max} = 10{,}000$ to 50,000 eV (10–50 keV) are made to strike a piece of metal. The electromagnetic radiation produced by this sudden deceleration of electrons is a continuous spectrum extending up to the maximum photon energy $h\nu = E_{max}$.

By far the brightest continuum spectra of electromagnetic radiation come from synchrotron radiation sources. These are not well known because they are predominantly used for research and only recently have they been considered for commercial and medical applications. Because any change in motion is an acceleration, circulating currents of electrons produce electromagnetic radiation. When these circulating electrons move at relativistic speeds (*i.e.*, those approaching the speed of light), the brightness of the radiation increases enormously. This radiation was first observed at the General Electric Company in 1947 in an electron synchrotron (hence the name of this radiation), which is a type of particle accelerator that forces relativistic electrons into circular orbits using powerful magnetic fields. The intensity of synchrotron radiation is further increased more than a thousandfold by wigglers and undulators that move the beam of relativistic electrons to and fro by means of other magnetic fields.

The conditions for generating bremsstrahlung as well as synchrotron radiation exist in nature in various forms. Acceleration and capture of charged particles by the gravitational field of a star, black hole, or galaxy is a source of energetic cosmic X rays. Gamma rays are produced in other kinds of cosmic objects—namely, supernovae, neutron stars, and quasars.

Discrete-frequency sources and absorbers of electromagnetic radiation. These are commonly encountered in everyday life. Familiar examples of discrete-frequency electromagnetic radiation include the distinct colours of lamps filled with different fluorescent gases characteristic of advertisement signs, the colours of dyes and pigments, the bright yellow of sodium lamps, the blue-green hue of mercury lamps, and the specific colours of lasers.

Sources of electromagnetic radiation of specific frequency are typically atoms or molecules. Every atom or molecule can have certain discrete internal energies, which are called quantum states. An atom or molecule can therefore change its internal energy only by discrete amounts. By going from a higher to a lower energy state, a quantum $h\nu$ of electromagnetic radiation is emitted of a magnitude that is precisely the energy difference between the higher and lower state. Absorption of a quantum $h\nu$ brings the atom from a lower to a higher state if $h\nu$ matches the energy difference. All like atoms are identical, but all different chemical elements of the periodic table have their own specific set of possible internal energies. Therefore, by measuring the characteristic and discrete electromagnetic radiation that is either emitted or absorbed by atoms or molecules, one can identify which kind of atom or molecule is giving off or absorbing the radiation. This provides a means of determining the chemical composition of substances. Since one cannot subject a piece of a distant star to conventional chemical analysis, studying the emission or absorption of starlight is the only way to determine the composition of stars or of interstellar gases and dust.

Internal energy states

The Sun, for example, not only emits the continuous spectrum of radiation that originates from its hot surface but also emits discrete radiation quanta $h\nu$ that are characteristic of its atomic composition. Many of the elements can be detected at the solar surface, but the most abundant is helium. This is so because helium is the end product of the nuclear fusion reaction that is the fundamental energy source of the Sun. This particular element was named helium (from the Greek word *helios*, meaning "Sun") because its existence was first discovered by its characteristic absorption energies in the Sun's spectrum. The helium of the cooler outer parts of the solar atmosphere absorbs the characteristic light frequencies from the lower and hotter regions of the Sun.

The characteristic and discrete energies $h\nu$ found as emission and absorption of electromagnetic radiation by atoms and molecules extend to X-ray energies. As high-energy electrons strike the piece of metal in an X-ray tube, electrons are knocked out of the inner energy shell of the atoms. These vacancies are then filled by electrons from the second or third shell; emitted in the process are X rays having $h\nu$ values that correspond to the energy differences of the shells. One therefore observes not only the continuous spectrum of the bremsstrahlung discussed above but also X-ray emissions of discrete energies $h\nu$ that are characteristic of the specific elemental composition of the metal struck by the energetic electrons in the X-ray tube.

The discrete electromagnetic radiation energies $h\nu$ emitted or absorbed by all substances reflect the discreteness of the internal energies of all material things. This means that window glass and water are transparent to visible light; they cannot absorb these visible light quanta because their internal energies are such that no energy difference between a higher and a lower internal state matches the energy $h\nu$ of visible light. Figure 3 shows as an example the coefficient of absorption of water as a function of frequency ν of electromagnetic radiation. Above the scale of frequencies, the corresponding scales of photon energy $h\nu$ and wavelength λ are given. An absorption coefficient $\alpha = 10^{-4}$ cm^{-1} means that the intensity of electromagnetic radiation is only one-third its original value after passing through 100 metres of water. When $\alpha = 1$ cm^{-1}, only a layer one centimetre thick is needed to decrease the intensity to one-third its original value, and, for $\alpha = 10^{3}$ cm, a layer of water having a thickness of this page is sufficient to attenuate electromagnetic radiation by that much. The transparency of water to visible light, marked by the vertical dashed lines, is a remarkable feature that is significant for life on Earth.

Transparency of water to visible light

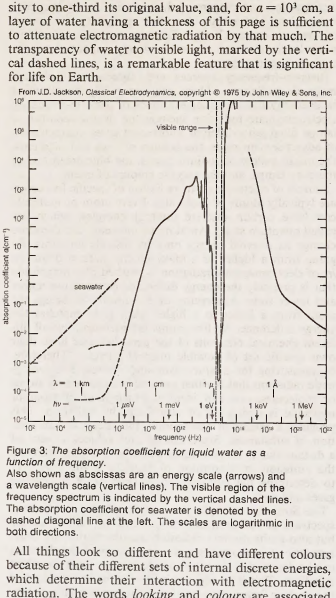

Figure 3: *The absorption coefficient for liquid water as a function of frequency.*
Also shown as abscissas are an energy scale (arrows) and a wavelength scale (vertical lines). The visible region of the frequency spectrum is indicated by the vertical dashed lines. The absorption coefficient for seawater is denoted by the dashed diagonal line at the left. The scales are logarithmic in both directions.

All things look so different and have different colours because of their different sets of internal discrete energies, which determine their interaction with electromagnetic radiation. The words *looking* and *colours* are associated with the human detectors of electromagnetic radiation, the eyes. Since there are instruments available for detecting electromagnetic radiation of any frequency, one can imagine that things "look" different at all energies of the spectrum because different materials have their own characteristic sets of discrete internal energies. Even the nuclei of atoms are composites of other elementary particles and thus can be excited to many discrete internal energy states. Since nuclear energies are much larger than atomic energies, the energy differences between internal energy states are substantially larger, and the corresponding electromagnetic radiation quanta $h\nu$ emitted or absorbed when nuclei change their energies are even bigger than those of X rays. Such quanta given off or absorbed by atomic nuclei are called gamma rays (see *The electromagnetic spectrum* above).

PROPERTIES AND BEHAVIOUR

Scattering, reflection, and refraction. If a charged particle interacts with an electromagnetic wave, it experiences a force proportional to the strength of the electric field and thus is forced to change its motion in accordance with the frequency of the electric field wave. In doing so, it becomes a source of electromagnetic radiation of the same frequency, as described in the previous section. The energy for the work done in accelerating the charged particle and emitting this secondary radiation comes from and is lost by the primary wave. This process is called scattering.

Since the energy density of the electromagnetic radiation is proportional to the square of the electric field strength and the field strength is caused by acceleration of a charge, the energy radiated by such a charge oscillator increases with the square of the acceleration. On the other hand, the acceleration of an oscillator depends on the frequency of the back-and-forth oscillation. The acceleration increases with the square of the frequency. This leads to the important result that the electromagnetic energy radiated by an oscillator increases very rapidly—namely, with the square of the square or, as one says, with the fourth power of the frequency. Doubling the frequency thus produces an increase in radiated energy by a factor of 16.

This rapid increase in scattering with the frequency of electromagnetic radiation can be seen on any sunny day: it is the reason the sky is blue and the setting Sun is red. The higher-frequency blue light from the Sun is scattered much more by the atoms and molecules of the Earth's atmosphere than is the lower-frequency red light. Hence the light of the setting Sun, which passes through a thick layer of atmosphere, has much more red than yellow or blue light, while light scattered from the sky contains much more blue than yellow or red light.

The process of scattering, or reradiating part of the electromagnetic wave by a charge oscillator, is fundamental to understanding the interaction of electromagnetic radiation with solids, liquids, or any matter that contains a very large number of charges and thus an enormous number of charge oscillators. This also explains why a substance that has charge oscillators of certain frequencies absorbs and emits radiation of those frequencies.

Significance of the scattering process

When electromagnetic radiation falls on a large collection of individual small charge oscillators, as in a piece of glass or metal or a brick wall, all of these oscillators perform oscillations in unison, following the beat of the electric wave. As a result, all the oscillators emit secondary radiation in unison (or coherently), and the total secondary radiation coming from the solid consists of the sum of all these secondary coherent electromagnetic waves. This sum total yields radiation that is reflected from the surface of the solid and radiation that goes into the solid at a certain angle with respect to the normal of (*i.e.*, a line perpendicular to) the surface. The latter is the refracted radiation that may be attenuated (absorbed) on its way through the solid.

Superposition and interference. When two electromagnetic waves of the same frequency superpose in space, the resultant electric and magnetic field strength of any point of space and time is the sum of the respective fields of the two waves. When one forms the sum, both the magnitude and the direction of the fields need be considered, which means that they sum like vectors. In the special case when two equally strong waves have their fields in the same direction in space and time (*i.e.*, when they are in phase), the resultant field is twice that of each individual wave. The resultant intensity, being proportional to the square of the field strength, is therefore not two but four times the intensity of each of the two superposing waves.

By contrast, the superposition of a wave that has an electric field in one direction (positive) in space and time with a wave of the same frequency having an electric field in the opposite direction (negative) in space and time leads to cancellation and no resultant wave at all (zero intensity). Two waves of this sort are termed out of phase. The first example, that of in-phase superposition yielding four times the individual intensity, constitutes what is called constructive interference. The second example, that of out-of-phase superposition yielding zero intensity, is destructive interference. Since the resultant field at any point and time is the sum of all individual fields at that point and time, these arguments are easily extended to any number of superposing waves. One finds constructive, destructive, or partial interference for waves having the same frequency and given phase relationships.

Constructive and destructive interference

Propagation and coherence. Once generated, an electromagnetic wave is self-propagating because a time-varying electric field produces a time-varying magnetic field and vice versa. When an oscillating current in an antenna is switched on for, say, eight minutes, then the beginning of the electromagnetic train reaches the Sun just when the antenna is switched off because it takes a few seconds more than eight minutes for electromagnetic radiation to reach the Sun. This eight-minute wave train, which is as long as the Sun–Earth distance, then continues to travel with the speed of light past the Sun into the space beyond.

Except for radio waves transmitted by antennas that are switched on for many hours, most electromagnetic waves comes in many small pieces. The length and duration of a wave train are called coherence length and coherence time, respectively. Light from the Sun or from a light bulb comes in many tiny bursts lasting about a millionth of a second and having a coherence length of about one centimetre. The discrete radiant energy emitted by an atom as it changes its internal energy can have a coherence length several hundred times longer (one to 10 metres) unless the radiating atom is disturbed by a collision.

Coherence length and coherence time

The time and space at which the electric and magnetic fields have a maximum value or are zero between the reversal of their directions are different for different wave trains. It is therefore clear that the phenomenon of interference can arise only from the superposition of part of a wave train with itself. This can be accomplished, for instance, with a half-transparent mirror that reflects half the intensity and transmits the other half of each of the billion billion wave trains of a given light source, say, a yellow sodium discharge lamp. One can allow one of these half beams to travel in direction A and the other in direction B, as shown in Figure 4. By reflecting each half beam back, one can then superpose the two half beams and observe the resultant total. If one half beam has to travel a path ½ wavelength or 3/2 or 5/2 wavelength longer than the other, then the superposition yields no light at all because the electric and magnetic fields of every half wave train in the two half beams point in opposite directions and their sum is therefore zero. The important point is that cancellation occurs between each half wave train and its mate. This is an example of destructive interference. By adjusting the path lengths A and B such that they are equal or differ by λ, 2λ, $3\lambda \ldots$, the electric and magnetic fields of each half wave train and its mate add when they are superposed. This is constructive interference, and, as a result, one sees strong light.

The interferometer discussed above and represented in Figure 4 was designed by the American physicist Albert A. Michelson in 1880 (while he was studying with Hermann von Helmholtz in Berlin) for the purpose of measuring the effect on the speed of light of the motion of the ether through which light was believed to travel (see below *The electromagnetic wave and field concept*).

Speed of electromagnetic radiation and the Doppler effect. Electromagnetic radiation, or in modern terminology the photons *hv*, always travel in free space with the universal speed *c*—*i.e.*, the speed of light. This is actually a very puzzling situation which was first experimentally verified by Michelson and Edward Williams Morley, another American scientist, in 1887 and which is the basic

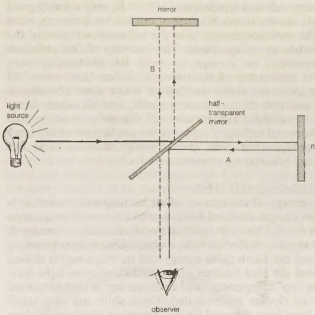

Figure 4: Michelson interferometer.

axiom of Albert Einstein's theory of relativity. Although there is no doubt that it is true, the situation is puzzling because it is so different from the behaviour of normal particles; that is to say, for little or not so little pieces of matter. When one chases behind a normal particle (*e.g.*, an airplane) or moves in the opposite direction toward it, one certainly will measure very different speeds of the airplane relative to oneself. One would detect a very small relative speed in the first case and a very large one in the second. Moreover, a bullet shot forward from the airplane and another toward the back would appear to be moving with different speeds relative to oneself. This would not at all be the case when one measures the speed of electromagnetic radiation: irrespective of one's motion or that of the source of the electromagnetic radiation, any measurement by a moving observer will result in the universal speed of light. This must be accepted as a fact of nature.

What happens to pitch or frequency when the source is moving toward the observer or away from him? It has been established from sound waves that the frequency is higher when a sound source is moving toward the observer and lower when it is moving away from him. This is the Doppler effect, named after the Austrian physicist Christian Doppler, who first described the phenomenon in 1842. Doppler predicted that the effect also occurs with electromagnetic radiation and suggested that it be used for measuring the relative speeds of stars. This means that a characteristic blue light emitted, for example, by an excited helium atom as it changes from a higher to a lower internal energy state would no longer appear blue when one looks at this light coming from helium atoms that move very rapidly away from the Earth with, say, a galaxy. When the speed of such a galaxy away from the Earth is large, the light may appear yellow; if the speed is still larger, it may appear red or even infrared. This is actually what happens, and the speed of galaxies as well as of stars relative to the Earth is measured from the Doppler shift of characteristic atomic radiation energies *hv*.

COSMIC BACKGROUND ELECTROMAGNETIC RADIATION

As one measures the relative speeds of galaxies using the Doppler shift of characteristic radiation emissions, one finds that all galaxies are moving away from one another. Those that are moving the fastest are systems that are the farthest away (Hubble's law). The speeds and distances give the appearance of an explosion. Extrapolating backward in time, one obtains an estimate as to when this explosion, dubbed the big bang, might have occurred. This time is calculated to be somewhere between 15 and 20 billion years ago, which is considered to be the age of the universe. From this early stage onward, the universe expanded and cooled. The American scientists Robert W. Wilson and Arno Penzias determined in 1965 that the whole universe can be conceived of as an expanding blackbody filled with electromagnetic radiation which now

The universe as an expanding blackbody

corresponds to a temperature of 2.74 K, only a few degrees above absolute zero. Because of this low temperature, most of the radiation energy is in the microwave region of the electromagnetic spectrum. The intensity of this radiation corresponds, on average, to about 400 photons in every cubic centimetre of the universe. It has been estimated that there are about one billion times more photons in the universe than electrons, nuclei, and all other things taken together. The presence of this microwave cosmic background radiation supports the predictions of big-bang cosmology. (For more specific information on these and related matters, see COSMOS, THE.)

EFFECT OF GRAVITATION

The energy of the quanta of electromagnetic radiation is subject to gravitational forces just like a mass of magnitude $m = h\nu/c^2$. This is so because the relationship of energy E and mass m is $E = mc^2$. As a consequence, light traveling toward the Earth gains energy and its frequency is shifted toward the blue (shorter wavelengths), whereas light traveling "up" loses energy and its frequency is shifted toward the red (longer wavelengths). These shifts are very small but have been detected by the American physicists Robert V. Pound and Glen A. Rebka.

The effect of gravitation on light increases with the strength of the gravitational attraction. Thus, a light beam from a distant star does not travel along a straight line when passing a star like the Sun but is deflected toward it. This deflection can be strong around very heavy cosmic objects, which then distort the light path acting as a gravitational lens.

Under extreme conditions the gravitational force of a cosmic object can be so strong that no electromagnetic radiation can escape the gravitational pull. Such an object, called a black hole, is therefore not visible and its presence can only be detected by its gravitational effect on other visible objects in its vicinity. (For additional information, see COSMOS, THE; PHYSICAL SCIENCES, THE: *Astronomy*.)

THE GREENHOUSE EFFECT OF THE ATMOSPHERE

The temperature of the terrestrial surface environment is controlled not only by the Sun's electromagnetic radiation but also in a sensitive way by the Earth's atmosphere. As noted earlier, each substance absorbs and emits electromagnetic radiation of some energies $h\nu$ and does not do so in other ranges of energy. These regions of transparency and opaqueness are governed by the particular distribution of internal energies of the substance.

The Earth's atmosphere acts much like the glass panes of a greenhouse: it allows sunlight, particularly its visible range, to reach and warm the Earth, but it largely inhibits the infrared radiation emitted by the heated terrestrial surface from escaping into space. Figure 5 shows the absorption of the Earth's atmosphere for various frequencies and wavelengths of electromagnetic radiation. Since the atmosphere becomes thinner and thinner with increasing altitude above the Earth, there is less atmospheric absorption in the higher regions of the atmosphere. At an altitude of 100 kilometres, the fraction of atmosphere is one 10-millionth of that on the ground. Figure 5 shows the altitude at which the intensity of electromagnetic radiation of certain frequencies coming from space is attenuated to one-half of its original value. There are regions of strong absorption and "windows" of transmission. Below 10 million hertz (10^7 Hz), the absorption is caused by the ionosphere, a layer in which atoms and molecules in the atmosphere are ionized by the Sun's ultraviolet radiation. In the infrared region, the absorption is caused by molecular vibrations and rotations. In the ultraviolet and X-ray regions, the absorption is due to electronic excitations in atoms and molecules. The window of transmission for visible light can be seen near the centre of the diagram.

Infrared-absorbing gases in the atmosphere

Without water vapour and carbon dioxide (CO_2), which are, together with certain industrial pollutants, the main infrared-absorbing species in the atmosphere, the Earth would experience the extreme temperature variations between night and day that occur on the Moon. The Earth would then be a frozen planet, like Mars, with an average temperature of 200 K, and not be able to support life.

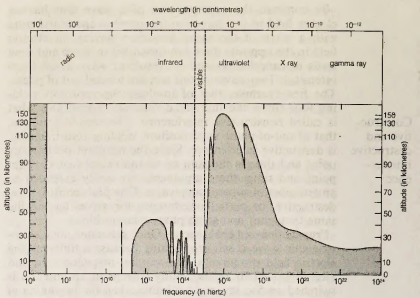

Figure 5: *Atmospheric absorption of electromagnetic radiation.* The intensity of electromagnetic radiation of certain frequencies coming from space is attenuated by the Earth's atmosphere to half of its original value at the altitudes shown here.

Adapted from "The New Astrophysics" by M. Longair in P. Davies (ed.), *The New Physics*, © Cambridge University Press, 1989; after F. Gasconi, H. Gursky, and L.P. van Speybroeck in "Observational Techniques in X-Ray Astronomy," reproduced, with permission, from the *Annual Review of Astronomy and Astrophysics*, vol. 6, © 1968 by Annual Reviews Inc.

Scientists believe that the Earth's temperature and climate in general will be affected as the composition of the atmosphere is altered by an increased release and accumulation of carbon dioxide and other gaseous pollutants (for a detailed discussion, see CLIMATE AND WEATHER: *Climate and life: Impact of human activities on climate;* HYDROSPHERE, THE: *Impact of human activities on the hydrosphere: Buildup of greenhouse gases*).

Forms of electromagnetic radiation

Electromagnetic radiation appears in a wide variety of forms and manifestations. Yet, these diverse phenomena are understood to comprise a single aspect of nature, following simple physical principles. Common to all forms is the fact that electromagnetic radiation interacts with and is generated by electric charges. The apparent differences in the phenomena arise from the question in which environment and under what circumstances can charges respond on the time scale of the frequency ν of the radiation.

At smaller frequencies ν (smaller than 10^{12} hertz), electric charges typically are the freely moving electrons in the metal components of antennas or the free electrons and ions in space that give rise to phenomena related to radio waves, radar waves, and microwaves. At higher frequencies (10^{12} to 5×10^{14} hertz), in the infrared region of the spectrum, the moving charges are primarily associated with the rotations and vibrations of molecules and the motions of atoms bonded together in materials. Electromagnetic radiation in the visible range to X rays have frequencies that correspond to charges within atoms, whereas gamma rays are associated with frequencies of charges within atomic nuclei. The characteristics of electromagnetic radiation occurring in the different regions of the spectrum are described in this section.

RADIO WAVES

Radio waves are used for wireless transmission of sound messages, or information, for communication, as well as for maritime and aircraft navigation. The information is imposed on the electromagnetic carrier wave as amplitude modulation (AM) or as frequency modulation (FM) or in digital form (pulse modulation). Transmission therefore involves not a single-frequency electromagnetic wave but rather a frequency band whose width is proportional to the information density. The width is about 10,000 Hz for telephone, 20,000 Hz for high-fidelity sound, and five megahertz (MHz = one million hertz) for high-definition television. This width and the decrease in efficiency of generating electromagnetic waves with decreasing fre-

quency sets a lower frequency limit for radio waves near 10,000 Hz.

Because electromagnetic radiation travels in free space in straight lines, scientists questioned the efforts of the Italian physicist and inventor Guglielmo Marconi to develop long-range radio. The curvature of the Earth limits the line-of-sight distance from the top of a 100-metre (330-foot) tower to about 30 kilometres (19 miles). Marconi's unexpected success in transmitting messages over more than 2,000 kilometres led to the discovery of the Kennelly-Heaviside layer, more commonly known as the ionosphere. This region is an approximately 300-kilometre-thick layer starting about 100 kilometres above the Earth's surface in which the atmosphere is partially ionized by ultraviolet light from the Sun, giving rise to enough electrons and ions to affect radio waves. Because of the Sun's involvement, the height, width, and degree of ionization of the stratified ionosphere vary from day to night and from summer to winter.

Radio waves transmitted by antennas in certain directions are bent or even reflected back to Earth by the ionosphere, as illustrated in Figure 6. They may bounce off the Earth and be reflected by the ionosphere repeatedly, making radio transmission around the globe possible. Long-distance communication is further facilitated by the so-called ground wave. This form of electromagnetic wave closely follows the surface of the Earth, particularly over water, as a result of the wave's interaction with the terrestrial surface. The range of the ground wave (up to 1,600 kilometres) and the bending and reflection of the sky wave by the ionosphere depend on the frequency of the waves. Under normal ionospheric conditions 40 MHz is the highest-frequency radio wave that can be reflected from the ionosphere. The strong absorption of the ionosphere below 10 MHz is shown in Figure 5. In order to accommodate the large band width of transmitted signals, television frequencies are necessarily higher than 40 MHz. Television transmitters must therefore be placed on high towers or on hilltops.

Ground waves

As a radio wave travels from the transmitting to the receiving antenna, it may be disturbed by reflections from buildings and other large obstacles. Disturbances arise when several such reflected parts of the wave reach the receiving antenna and interfere with the reception of the wave. Radio waves can penetrate nonconducting materials such as wood, bricks, and concrete fairly well. They cannot pass through electrical conductors such as water or metals. Above $\nu = 40$ MHz, radio waves from deep space can penetrate the Earth's atmosphere. This makes radio astronomy observations with ground-based telescopes possible.

Whenever transmission of electromagnetic energy from one location to another is required with minimal energy loss and disturbance, the waves are confined to a limited region by means of wires, coaxial cables, and, in the microwave region, waveguides. Unguided or wireless transmission is naturally preferred when the locations of receivers are unspecified or too numerous, as in the case of radio and television communications. Cable television, as the name implies, is an exception. In this case electromagnetic radiation is transmitted by a coaxial cable system to users either from a community antenna or directly from broadcasting stations. The shielding of this guided transmission from disturbances provides high-quality signals.

Transmission via wires, coaxial cables, and waveguides

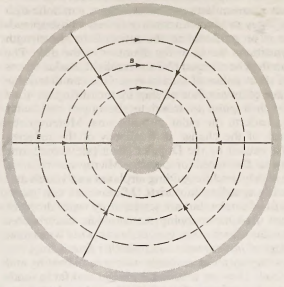

Figure 7: *Cross section of a coaxial cable carrying high-frequency current.*
Electric field lines *E* (solid) and magnetic field lines *B* (dashed) are mutually perpendicular and perpendicular to the electromagnetic wave propagation, which is toward the viewer.

Figure 7 shows the electric field E (solid lines) and the magnetic field B (dashed lines) of an electromagnetic wave guided by a coaxial cable. There is a potential difference between the inner and outer conductors and so electric field lines E extend from one conductor to the other, represented here in cross section. The conductors carry opposite currents that produce the magnetic field lines B. The electric and magnetic fields are perpendicular to each other and perpendicular to the direction of propagation, as is characteristic of the electromagnetic waves illustrated in Figure 2. At any cross section viewed, the directions of the E and B field lines change to their opposite with the frequency ν of the radiation. This direction reversal of the fields does not change the direction of propagation along the conductors. The speed of propagation is again the universal speed of light if the region between the conductors consists of air or free space.

A combination of radio waves and strong magnetic fields is used by magnetic resonance imaging (MRI) to produce diagnostic pictures of parts of the human body and brain without apparent harmful effects. This imaging technique has thus found increasingly wider application in medicine (see also RADIATION: *Imaging techniques*).

Extremely low-frequency (ELF) waves are of interest for communications systems for submarines. The relatively weak absorption by seawater of electromagnetic radiation at low frequencies and the existence of prominent resonances of the natural cavity formed by the Earth and the ionosphere make the range between 5 and 100 Hz attractive for this application.

There is evidence that ELF waves and the oscillating magnetic fields that occur near electric power transmission lines or electric heating blankets have adverse effects on human health and the electrochemical balance of the

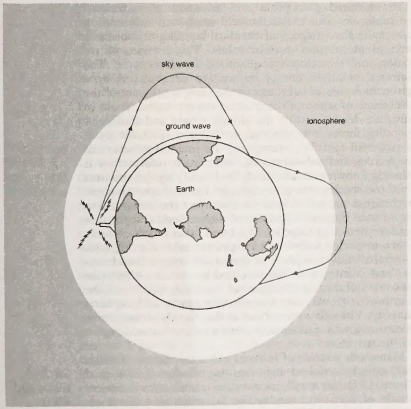

Figure 6: Radio-wave transmission reaching beyond line of sight by means of the sky wave reflected by the ionosphere and by means of the ground wave (see text).

brain. Prolonged exposure to low-level and low-frequency magnetic fields have been reported to increase the risk of developing leukemia, lymphoma, and brain cancer in children.

MICROWAVES

The microwave region extends from 1,000 to 300,000 MHz (or 30-centimetre to one-millimetre wavelengths). Although microwaves were first produced and studied in 1886 by Hertz, their practical application had to await the invention of suitable generators, such as the klystron and magnetron.

Use in high-speed telegraphic data transmissions

Microwaves are the principal carriers of high-speed telegraphic data transmissions between stations on the Earth and also between ground-based stations and satellites and space probes. A system of synchronous satellites about 36,000 kilometres above the Earth is used for international broadband telegraphy of all kinds of communications—*e.g.*, television, telephone, and telefacsimile (FAX).

Microwave transmitters and receivers are parabolic dish antennas. They produce microwave beams whose spreading angle is proportional to the ratio of the wavelength of the constituent waves to the diameter of the dish. The beams can thus be directed like a searchlight. Radar beams consist of short pulses of microwaves. One can determine the distance of an airplane or ship by measuring the time it takes such a pulse to travel to the object and, after reflection, back to the radar dish antenna. Moreover, by making use of the change in frequency of the reflected wave pulse caused by the Doppler effect (see above), one can measure the speed of objects. Microwave radar is therefore widely used for guiding airplanes and vessels and for detecting speeding motorists. Microwaves can penetrate clouds of smoke, but are scattered by water droplets, and so are used for mapping meteorologic disturbances and in weather forecasting (see CLIMATE AND WEATHER: *Meteorological measurement and weather forecasting*).

Microwaves play an increasingly wide role in heating and cooking food. They are absorbed by water and fat in foodstuffs (*e.g.*, in the tissue of meats) and produce heat from the inside. In most cases, this reduces the cooking time a hundredfold. Such dry objects as glass and ceramics, on the other hand, are not heated in the process, and metal foils are not penetrated at all.

The heating effect of microwaves destroys living tissue when the temperature of the tissue exceeds 43° C (109° F). Accordingly, exposure to intense microwaves in excess of 20 milliwatts of power per square centimetre of body surface is harmful. The lens of the human eye is particularly affected by waves with a frequency of 3,000 MHz, and repeated and extended exposure can result in cataracts. Radio waves and microwaves of far less power (microwatts per square centimetre) than the 10–20 milliwatts per square centimetre needed to produce heating in living tissue can have adverse effects on the electrochemical balance of the brain and the development of a fetus if these waves are modulated or pulsed at low frequencies between 5 and 100 hertz, which are of the same magnitude as brain wave frequencies.

Microwave sources

Various types of microwave generators and amplifiers have been developed. Vacuum-tube devices, the klystron and the magnetron, continue to be used on a wide scale, especially for higher-power applications. Klystrons are primarily employed as amplifiers in radio relay systems and for dielectric heating, while magnetrons have been adopted for radar systems and microwave ovens. (For a detailed discussion of these devices, see ELECTRONICS: *Principal devices and components: Electron tubes*.) Solid-state technology has yielded several devices capable of producing, amplifying, detecting, and controlling microwaves. Notable among these are the Gunn diode and the tunnel (or Esaki) diode. Another type of device, the maser (acronym for "microwave amplification by stimulated emission of radiation") has proved useful in such areas as radio astronomy, microwave radiometry, and long-distance communications.

Astronomers have discovered what appears to be natural masers in some interstellar clouds. Observations of radio radiation from interstellar hydrogen (H_2) and certain other molecules indicate amplification by the maser process. Also, as was mentioned above, microwave cosmic background radiation has been detected and is considered by many to be the remnant of the primeval fireball postulated by the big-bang cosmological model.

INFRARED RADIATION

Beyond the red end of the visible range but at frequencies higher than those of radar waves and microwaves is the infrared region of the electromagnetic spectrum, between frequencies of 10^{12} and 5×10^{14} Hz (or wavelengths from 0.1 to 7.5×10^{-5} centimetre). William Herschel, a German-born British musician and self-taught astronomer, discovered this form of radiation in 1800 by exploring, with the aid of a thermometer, sunlight dispersed into its colours by a glass prism. Infrared radiation is absorbed and emitted by the rotations and vibrations of chemically bonded atoms or groups of atoms and thus by many kinds of materials. For instance, window glass that is transparent to visible light absorbs infrared radiation by the vibration of its constituent atoms. Infrared radiation is strongly absorbed by water and by the atmosphere, as shown in Figures 3 and 5, respectively. Although invisible to the eye, infrared radiation can be detected as warmth by the skin. Nearly 50 percent of the Sun's radiant energy is emitted in the infrared region of the electromagnetic spectrum, with the rest primarily in the visible region.

Atmospheric haze and certain pollutants that scatter visible light are nearly transparent to parts of the infrared spectrum because the scattering efficiency increases with the fourth power of the frequency. Infrared photography of distant objects from the air takes advantage of this phenomenon. For the same reason, infrared astronomy enables researchers to observe cosmic objects through large clouds of interstellar dust that scatter infrared radiation substantially less than visible light. However, since water vapour, ozone, and carbon dioxide in the atmosphere absorb large parts of the infrared spectrum most infrared astronomical observations are carried out at high altitude by balloons, rockets, or spacecraft.

An infrared photograph of a landscape enhances objects according to their heat emission: blue sky and water appear nearly black, whereas green foliage and unexposed skin show up brightly. Infrared photography can reveal pathological tissue growths (thermography) and defects in electronic systems and circuits due to their increased emission of heat.

The infrared absorption and emission characteristics of molecules and materials yield important information about the size, shape, and chemical bonding of molecules and of atoms and ions in solids. The energies of rotation and vibration are quantized in all systems. The infrared radiation energy $h\nu$ emitted or absorbed by a given molecule or substance is therefore a measure of the difference of some of the internal energy states. These in turn are determined by the atomic weight and molecular bonding forces. For this reason, infrared spectroscopy is a powerful tool for determining the internal structure of molecules and substances or, when such information is already known and tabulated, for identifying the amounts of those species in a given sample. Infrared spectroscopic techniques are often used to determine the composition and hence the origin and age of archaeological specimens and for detecting forgeries of art and other objects, which, when inspected under visible light, resemble the originals.

Infrared radiation plays an important role in heat transfer and is integral to the so-called greenhouse effect (see above), influencing the thermal radiation budget of the Earth on a global scale and affecting nearly all biospheric activity. Virtually every object at the Earth's surface emits electromagnetic radiation primarily in the infrared region of the spectrum.

Infrared LEDs and lasers

Man-made sources of infrared radiation include, besides hot objects, infrared light-emitting diodes (LEDs) and lasers. LEDs are small, inexpensive optoelectronic devices made of such semiconducting materials as gallium arsenide. Infrared LEDs are employed as optoisolators and as light sources in some fibre-optics-based communications systems (see ELECTRONICS: *Principal devices and compo-*

nents: Optoelectronic devices). Powerful optically pumped infrared lasers have been developed using carbon dioxide and carbon monoxide. Carbon dioxide infrared lasers are used to induce and alter chemical reactions and in isotope separation. They also are employed in LIDAR (light radar) systems. Other applications of infrared light include its use in the rangefinders of automatic self-focusing cameras, security alarm systems, and night-vision optical instruments.

Instruments for detecting infrared radiation include heat-sensitive devices such as thermocouple detectors, bolometers (some of these are cooled to temperatures close to absolute zero so that the thermal radiation of the detector system itself is greatly reduced), photovoltaic cells, and photoconductors. The latter are made of semiconductor materials (*e.g.*, silicon and lead sulfide) whose electrical conductance increases when exposed to infrared radiation.

VISIBLE RADIATION

Visible light is the most familiar form of electromagnetic radiation and makes up that portion of the spectrum to which the eye is sensitive. This span is very narrow; the frequencies of violet light are only about twice those of red. The corresponding wavelengths extend from 7×10^{-5} centimetre (red) to 4×10^{-5} centimetre (violet). The energy of a photon from the centre of the visible spectrum (yellow) is $h\nu = 2.2$ eV. This is one million times larger than the energy of a photon of a television wave and one billion times larger than that of radio waves in general (see Figure 1).

Life on Earth could not exist without visible light, which represents the peak of the Sun's spectrum and close to one-half of all of its radiant energy. Visible light is essential for photosynthesis, which enables plants to produce the carbohydrates and proteins that are the food sources for animals. Coal and oil are sources of energy accumulated from sunlight in plants and microorganisms millions of years ago, and hydroelectric power is extracted from one step of the hydrologic cycle kept in motion by sunlight at the present time.

Considering the importance of visible sunlight for all aspects of terrestrial life, one cannot help being awed by the dramatically narrow window in the atmospheric absorption shown in Figure 5 and in the absorption spectrum of water in Figure 3. The remarkable transparency of water centred in the narrow regime of visible light, indicated by vertical dashed lines in Figure 3, is the result of the characteristic distribution of internal energy states of water. Absorption is strong toward the infrared on account of molecular vibrations and intermolecular oscillations. In the ultraviolet region, absorption of radiation is caused by electronic excitations. Light of frequencies having absorption coefficients larger than $\alpha = 10\ \text{cm}^{-1}$ cannot even reach the retina of the human eye because its constituent liquid consists mainly of water that absorbs such frequencies of light.

Conversion of solar energy into electricity

Since the 1970s an increasing number of devices have been developed for converting sunlight into electricity. Unlike various conventional energy sources, solar energy does not become depleted by use and does not pollute the environment. Two branches of development may be noted—namely, photothermal and photovoltaic technologies. In photothermal devices, sunlight is used to heat a substance, as, for example, water, to produce steam with which to drive a generator. Photovoltaic devices, on the other hand, convert the energy in sunlight directly to electricity by use of the photovoltaic effect in a semiconductor junction. Solar panels consisting of photovoltaic devices made of gallium arsenide have conversion efficiencies of more than 20 percent and are used to provide electric power in many satellites and space probes. Large-area solar panels can be made with amorphous semiconductors that have conversion efficiencies of about 10 percent. Solar cells have replaced dry cell batteries in some portable electronic instruments, and solar energy power stations of one- to six-megawatts capacity have been built.

The intensity and spectral composition of visible light can be measured and recorded by essentially any process or property that is affected by light. Detectors make use of a photographic process based on silver halide, the photoemission of electrons from metal surfaces, the generation of electric current in a photovoltaic cell, and the increase in electrical conduction in semiconductors.

Glass fibres constitute an effective means of guiding and transmitting light. A beam of light is confined by total internal reflection to travel inside such an optical fibre, whose thickness may be anywhere between one hundredth of a millimetre and a few millimetres. Many thin optical fibres can be combined into bundles to achieve image reproduction. The flexibility of these fibres or fibre bundles permits their use in medicine for optical exploration of internal organs. Optical fibres connecting the continents provide the capability to transmit substantially larger amounts of information than other systems of international telecommunications. Another advantage of optical fibre communication systems is that transmissions cannot easily be intercepted and are not disturbed by lower atmospheric and stratospheric disturbances.

Optical fibres integrated with miniature semiconductor lasers and light-emitting diodes, as well as with light detector arrays and photoelectronic imaging and recording materials, form the building blocks of a new optoelectronics industry. Some familiar commercial products are optoelectronic copying machines, laser printers, compact disc players, FAX machines, optical recording media, and optical disc mass-storage systems of exceedingly high bit density.

ULTRAVIOLET RADIATION

The German physicist Johann Wilhelm Ritter, having learned of Herschel's discovery of infrared waves, looked beyond the violet end of the visible spectrum of the Sun and found (in 1801) that there exist invisible rays that darken silver chloride even more efficiently than visible light. This spectral region extending between visible light and X rays is designated ultraviolet. Sources of this form of electromagnetic radiation are hot objects like the Sun, synchrotron radiation sources, mercury or xenon arc lamps, and gaseous discharge tubes filled with gas atoms (*e.g.*, mercury, deuterium, or hydrogen) that have internal electron energy levels which correspond to the photons of ultraviolet light.

Fluorescence

When ultraviolet light strikes certain materials, it causes them to fluoresce—*i.e.*, they emit electromagnetic radiation of lower energy, such as visible light. The spectrum of fluorescent light is characteristic of a material's composition and thus can be used for screening minerals, detecting bacteria in spoiled food, identifying pigments, or detecting forgeries of artworks and other objects (the aged surfaces of ancient marble sculptures, for instance, fluoresce yellow-green, whereas a freshly cut marble surface fluoresces bright violet).

Optical instruments for the ultraviolet region are made of special materials, such as quartz, certain silicates, and metal fluorides, which are transparent at least in the near ultraviolet. Far-ultraviolet radiation is absorbed by nearly all gases and materials and thus requires reflection optics in vacuum chambers.

Ultraviolet radiation is detected by photographic plates and by means of the photoelectric effect in photomultiplier tubes. Also, ultraviolet radiation can be converted to visible light by fluorescence before detection.

The relatively high energy of ultraviolet light gives rise to certain photochemical reactions. This characteristic is exploited to produce cyanotype impressions on fabrics and for blueprinting design drawings. Here, the fabric or paper is treated with a mixture of chemicals that react upon exposure to ultraviolet light to form an insoluble blue compound. Electronic excitations caused by ultraviolet radiation also produce changes in the colour and transparency of photosensitive and photochromic glasses. Photochemical and photostructural changes in certain polymers constitute the basis for photolithography and the processing of the microelectronic circuits.

Although invisible to the eyes of humans and most vertebrates, near-ultraviolet light can be seen by many insects. Butterflies and many flowers that appear to have identical colour patterns under visible light are distinctly

different when viewed under the ultraviolet rays perceptible to insects.

An important difference between ultraviolet light and electromagnetic radiation of lower frequencies is the ability of the former to ionize, meaning that it can knock an electron out from atoms and molecules. All high-frequency electromagnetic radiation beyond the visible—*i.e.*, ultraviolet light, X rays, and gamma rays—is ionizing and therefore harmful to body tissues, living cells, and DNA (deoxyribonucleic acid). The harmful effects of ultraviolet light to humans and larger animals are mitigated by the fact that this form of radiation does not penetrate much further than the skin.

The body of a sunbather is struck by 10^{21} photons every second, and 1 percent of these, or more than a billion billion per second, are photons of ultraviolet radiation. Tanning and natural body pigments help to protect the skin to some degree, preventing the destruction of skin cells by ultraviolet light. Nevertheless, overexposure to the ultraviolet component of sunlight can cause skin cancer, cataracts of the eyes, and damage to the body's immune system. Fortunately a layer of ozone (O_3) in the stratosphere absorbs the most damaging ultraviolet rays, which have wavelengths of 2000 and 2900 angstroms (one angstrom [Å] = 10^{-10} metre), and attenuates those with wavelengths between 2900 and 3150 Å, as shown in Figure 5. Without this protective layer of ozone, life on Earth would not be possible. The ozone layer is produced at an altitude of about 10 to 50 kilometres above the Earth's surface by a reaction between upward-diffusing molecular oxygen (O_2) and downward-diffusing ionized atomic oxygen (O^+). Many scientists believe that this life-protecting stratospheric ozone layer is being reduced by chlorine atoms in chlorofluorocarbon (or Freon) gases released into the atmosphere by aerosol propellants, air-conditioner coolants, solvents used in the manufacture of electronic components, and other sources. (For more specific information, see ATMOSPHERE: *Composition of the present atmosphere: Effects of human activity on atmospheric composition and their ramifications: Depletion of stratospheric ozone.*)

Protective ozone layer

Ionized atomic oxygen, nitrogen, and nitric oxide are produced in the upper atmosphere by absorption of solar ultraviolet radiation. This ionized region is the ionosphere, which affects radio communications and reflects and absorbs radio waves of frequencies below 40 MHz (see Figure 5).

X RAYS

The German physicist Wilhelm Conrad Röntgen discovered X rays in 1895 by accident while studying cathode rays in a low-pressure gas discharge tube. (A few years later J.J. Thomson of England showed that cathode rays were electrons emitted from the negative electrode [cathode] of the discharge tube.) Röntgen noticed the fluorescence of a barium platinocyanide screen that happened to lie near the discharge tube. He traced the source of the hitherto undetected form of radiation to the point where the cathode rays hit the wall of the discharge tube, and mistakenly concluded from his inability to observe reflection or refraction that his new rays were unrelated to light. Because of his uncertainty about their nature, he called them X-radiation. This early failure can be attributed to the very short wavelengths of X rays (10^{-8} to 10^{-11} centimetre), which correspond to photon energies from 200 to 100,000 eV. In 1912 another German physicist, Max von Laue, realized that the regular arrangement of atoms in crystals should provide a natural grating of the right spacing (about 10^{-8} centimetre) to produce an interference pattern on a photographic plate when X rays pass through such a crystal. The success of this experiment, carried out by Walter Friedrich and Paul Knipping, not only identified X rays with electromagnetic radiation but also initiated the use of X rays for studying the detailed atomic structure of crystals. The interference of X rays diffracted in certain directions from crystals in so-called X-ray diffractometers, in turn, permits the dissection of X-radiation into its different frequencies, just as a prism diffracts and spreads the various colours of light. The spectral composition and characteristic frequencies of X rays emitted by a given X-ray source can thus be measured. As in optical spectroscopy, the X-ray photons emitted correspond to the differences of the internal electronic energies in atoms and molecules. Because of their much higher energies, however, X-ray photons are associated with the inner-shell electrons close to the atomic nuclei, whereas optical absorption and emission are related to the outermost electrons in atoms or in materials in general. Since the outer electrons are used for chemical bonding while the energies of inner-shell electrons remain essentially unaffected by atomic bonding, the identity and quantity of elements that make up a material are more accurately determined by the emission, absorption, or fluorescence of X rays than of photons of visible or ultraviolet light.

Röntgen's X-radiation

The contrast between body parts in medical X-ray photographs (radiographs) is produced by the different scattering and absorption of X rays by bones and tissues. Within months of Röntgen's discovery of X rays and his first X-ray photograph of his wife's hand, this form of electromagnetic radiation became indispensable in orthopedic and dental medicine. The use of X rays for obtaining images of the body's interior has undergone considerable development over the years and has culminated in the highly sophisticated procedure known as computerized axial tomography (CAT; see RADIATION: *Applications of radiation: Medical applications: Imaging techniques*).

Notwithstanding their usefulness in medical diagnosis, the ability of X rays to ionize atoms and molecules and their penetrating power make them a potential health hazard. Exposure of body cells and tissue to large doses of such ionizing radiation can result in abnormalities in DNA that may lead to cancer and birth defects. (For a detailed treatment of the effects of X rays and other forms of ionizing radiation on human health and the levels of such radiation encountered in daily life, see RADIATION: *Biologic effects of ionizing radiation.*)

X rays are produced in X-ray tubes by the deceleration of energetic electrons (bremsstrahlung) as they hit a metal target or by accelerating electrons moving at relativistic velocities in circular orbits (synchrotron radiation; see above). They are detected by their photochemical action in photographic emulsions or by their ability to ionize gas atoms: every X-ray photon produces a burst of electrons and ions, resulting in a current pulse. By counting the rate of such current pulses per second, the intensity of a flux of X rays can be measured. Instruments used for this purpose are called Geiger counters.

X-ray astronomy has revealed very strong sources of X rays in deep space. In the Milky Way Galaxy, of which the solar system is a part, the most intense sources are certain double star systems in which one of the two stars is thought to be either a compact neutron star or a black hole. The ionized gas of the circling companion star falls by gravitation into the compact star, generating X rays that may be more than 1,000 times as intense as the total amount of light emitted by the Sun. At the moment of their explosion, supernovae emit a good fraction of their energy in a burst of X rays.

Cosmic X-ray sources

GAMMA RAYS

Six years after the discovery of radioactivity (1896) by Henri Becquerel of France, the New Zealand-born British physicist Ernest Rutherford found that three different kinds of radiation are emitted in the decay of radioactive substances; these he called alpha, beta, and gamma rays in sequence of their ability to penetrate matter. The alpha particles were found to be identical with the nuclei of helium atoms and the beta rays were identified as electrons. In 1912 it was shown that the much more penetrating gamma rays have all the properties of very energetic electromagnetic radiation, or photons. Gamma-ray photons are between 10,000 and 10,000,000 times more energetic than the photons of visible light when they originate from radioactive atomic nuclei. Gamma rays with a million million times higher energy make up a very small part of the cosmic rays that reach the Earth from supernovae or from other galaxies. The origin of the most energetic gamma rays is not yet known.

During radioactive decay, an unstable nucleus usually emits alpha particles, electrons, gamma rays, and neutrinos spontaneously. In nuclear fission, the unstable nucleus breaks into fragments, which are themselves complex nuclei, along with such particles as neutrons and protons. The resultant stable nuclei or nuclear fragments are usually in a highly excited state and then reach their low-energy ground state by emitting one or more gamma rays. Such a decay scheme is shown schematically in Figure 8 for the unstable nucleus sodium-24 (^{24}Na). Much of what is known about the internal structure and energies of nuclei has been obtained from the emission or resonant absorption of gamma rays by nuclei. Absorption of gamma rays by nuclei can cause them to eject neutrons or alpha particles or it can even split a nucleus like a bursting bubble in what is called photodisintegration. A gamma particle hitting a hydrogen nucleus (that is, a proton), for example, produces a positive pi-meson and a neutron or a neutral pi-meson and a proton. Neutral pi-mesons, in turn, have a very brief mean life of 1.8×10^{-16} second and decay into two gamma rays of energy $h\nu \approx 70$ MeV. When an energetic gamma ray $h\nu > 1.02$ MeV passes a nucleus, it may disappear while creating an electron–positron pair. Gamma photons interact with matter by discrete elementary processes that include resonant absorption, photodisintegration, ionization, scattering (Compton scattering), or pair production.

Photodisintegration

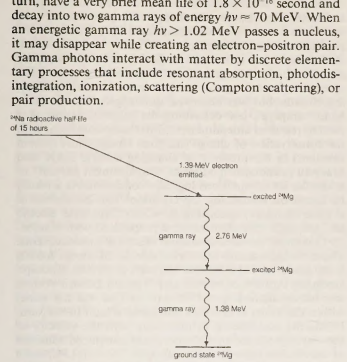

Figure 8: Decay scheme of a radioactive sodium-24 (^{24}Na) nucleus. With a half-life of 15 hours, it decays by beta decay to an excited magnesium-24 (^{24}Mg) nucleus. Two gamma rays are rapidly emitted and the excitation energy is carried off, whereby the stable ground state of magnesium-24 is reached.

Gamma rays are detected by their ability to ionize gas atoms or to create electron–hole pairs in semiconductors or insulators. By counting the rate of charge pulses or voltage pulses or by measuring the scintillation of the light emitted by the subsequently recombining electron–hole pairs, one can determine the number and energy of gamma rays striking an ionization detector or scintillation counter.

Both the specific energy of the gamma-ray photon emitted as well as the half-life of the specific radioactive decay process that yields the photon identify the type of nuclei at hand and their concentrations. By bombarding stable nuclei with neutrons, one can artificially convert more than 70 different stable nuclei into radioactive nuclei and use their characteristic gamma emission for purposes of identification, for impurity analysis of metallurgical specimens (neutron-activation analysis), or as radioactive tracers with which to determine the functions or malfunctions of human organs, to follow the life cycles of organisms, or to determine the effects of chemicals on biological systems and plants.

Penetrating power of gamma rays

The great penetrating power of gamma rays stems from the fact that they have no electric charge and thus do not interact with matter as strongly as do charged particles. Because of their penetrating power gamma rays can be used for radiographing holes and defects in metal castings and other structural parts. At the same time, this property makes gamma rays extremely hazardous. The lethal effect of this form of ionizing radiation makes it useful for sterilizing medical supplies that cannot be sanitized by boiling or for killing organisms that cause food spoilage. More than 50 percent of the ionizing radiation to which humans are exposed comes from natural radon gas, which is an end product of the radioactive decay chain of natural radioactive substances in minerals. Radon escapes from the ground and enters the environment in varying amounts.

Historical survey

DEVELOPMENT OF THE CLASSICAL RADIATION THEORY

The classical electromagnetic radiation theory "remains for all time one of the greatest triumphs of human intellectual endeavor." So said Max Planck in 1931, commemorating the 100th anniversary of the birth of the Scottish physicist James Clerk Maxwell, the prime originator of this theory. The theory was indeed of great significance, for it not only united the phenomena of electricity, magnetism, and light in a unified framework but also was a fundamental revision of the then-accepted Newtonian way of thinking about the forces in the physical universe. The development of the classical radiation theory constituted a conceptual revolution that lasted for nearly half a century. It began with the seminal work of the British physicist and chemist Michael Faraday, who published his article "Thoughts on Ray Vibrations" in *Philosophical Magazine* in May 1846, and came to fruition in 1888 when Hertz succeeded in generating electromagnetic waves at radio and microwave frequencies and measuring their properties.

Wave theory and corpuscular theory. The Newtonian view of the universe may be described as a mechanistic interpretation. All components of the universe, small or large, obey the laws of mechanics, and all phenomena are in the last analysis based on matter in motion. A conceptual difficulty in Newtonian mechanics, however, is the way in which the gravitational force between two massive objects acts over a distance across empty space. Newton did not address this question, but many of his contemporaries hypothesized that the gravitational force was mediated through an invisible and frictionless medium which Aristotle had called the ether (or aether). The problem is that everyday experience of natural phenomena shows mechanical things to be moved by forces which make contact. Any cause and effect without a discernable contact, or "action at a distance," contradicts common sense and has been an unacceptable notion since antiquity. Whenever the nature of the transmission of certain actions and effects over a distance was not yet understood, the ether was resorted to as a conceptual solution of the transmitting medium. By necessity, any description of how the ether functioned remained vague, but its existence was required by common sense and thus not questioned.

Notion of the ether

In Newton's day, light was one phenomenon, besides gravitation, whose effects were apparent at large distances from its source. Newton contributed greatly to the scientific knowledge of light. His experiments revealed that white light is a composite of many colours, which can be dispersed by a prism and reunited to again yield white light. The propagation of light along straight lines convinced him that it consists of tiny particles which emanate at high or infinite speed from the light source. The first observation from which a finite speed of light was deduced was made soon thereafter, in 1676, by the Danish astronomer Ole Rømer (see *Speed of light* below).

Observations of two phenomena strongly suggested that light propagates as waves. One of these involved interference by thin films, which was discovered in England independently by Robert Boyle and Robert Hooke. The other had to do with the diffraction of light in the geometric shadow of an opaque screen. The latter was also discovered by Hooke, who published a wave theory of light in 1665 to explain it.

The Dutch scientist Christiaan Huygens greatly improved the wave theory and explained reflection and refraction in terms of what is now called Huygens' principle. According to this principle (published in 1690), each point on a wave front in the hypothetical ether or in an optical medium is a source of a new spherical light wave and the wave front

Huygens' principle

is the envelope of all the individual wavelets that originate from the old wave front.

In 1669 another Danish scientist, Erasmus Bartholin, discovered the polarization of light by double refraction in Iceland spar (calcite). This finding had a profound effect on the conception of the nature of light. At that time, the only waves known were those of sound, which are longitudinal. It was inconceivable to both Newton and Huygens that light could consist of transverse waves in which vibrations are perpendicular to the direction of propagation. Huygens gave a satisfactory account of double refraction by proposing that the asymmetry of the structure of Iceland spar causes the secondary wavelets to be ellipsoidal instead of spherical in his wave front construction. Since Huygens believed in longitudinal waves, he failed, however, to understand the phenomena associated with polarized light. Newton, on the other hand, used these phenomena as the bases for an additional argument for his corpuscular theory of light. Particles, he argued in 1717, have "sides" and can thus exhibit properties that depend on the directions perpendicular to the direction of motion.

It may be surprising that Huygens did not make use of the phenomenon of interference to support his wave theory; but for him waves were actually pulses instead of periodic waves with a certain wavelength. One should bear in mind that the word wave may have a very different conceptual meaning and convey different images at various times to different people.

It took nearly a century before a new wave theory was formulated by the physicists Thomas Young of England and Augustin-Jean Fresnel of France. Based on his experiments on interference, Young realized for the first time that light is a transverse wave. Fresnel then succeeded in explaining all optical phenomena known at the beginning of the 19th century with a new wave theory. No proponents of the corpuscular light theory remained. Nonetheless, it is always satisfying when a competing theory is discarded on grounds that one of its principal predictions is contradicted by experiment. The corpuscular theory explained the refraction of light passing from a medium of given density to a denser one in terms of the attraction of light particles into the latter. This means the light velocity should be larger in the denser medium. Huygens' construction of wave fronts waving across the boundary between two optical media predicted the opposite—that is to say, a smaller light velocity in the denser medium. The measurement of the light velocity in air and water by Armand-Hippolyte-Louis Fizeau and independently by Jean-Bernard-Léon Foucault during the mid-19th century decided the case in favour of the wave theory (see *Speed of light* below).

The transverse wave nature of light implied that the ether must be a solid elastic medium. The larger velocity of light suggested, moreover, a great elastic stiffness of this medium; yet, it was recognized that all celestial bodies move through the ether without encountering such difficulties as friction. These conceptual problems remained unsolved until the beginning of the 20th century. (Ht.F.)

Relation between electricity and magnetism. As early as 1760 the Swiss-born mathematician Leonhard Euler suggested that the same ether that propagates light is responsible for electrical phenomena. In comparison with both mechanics and optics, however, the science of electricity was slow to develop. Magnetism was the one science that made progress in the Middle Ages, following the introduction from China into the West of the magnetic compass, but electromagnetism played little part in the scientific revolution of the 17th century. It was, however, the only part of physics in which very significant progress was made during the 18th century. By the end of that century the laws of electrostatics—the behaviour of charged particles at rest—were well known, and the stage was set for the development of the elaborate mathematical description first made by the French mathematician Siméon-Denis Poisson. There was no apparent connection of electricity with magnetism, except that magnetic poles, like electric charges, attract and repel with an inverse-square law force.

Following the discoveries in electrochemistry (the chemical effects of electrical current) by the Italian investigators Luigi Galvani, a physiologist, and Alessandro Volta, a physicist, interest turned to current electricity. A search was made by the Danish physicist Hans Christian Ørsted for some connection between electric currents and magnetism, and during the winter of 1819–20 he observed the effect of a current on a magnetic needle. Members of the French Academy learned about Ørsted's discovery in September 1820, and several of them began to investigate it further. Of these, the most thorough in both experiment and theory was the physicist André-Marie Ampère, who may be called the father of electrodynamics. The magnetic effect of a current had been observed earlier (1802) by an Italian jurist, Gian Domenico Romagnosi, but the announcement was published in an obscure newspaper.

The list of four fundamental empirical laws of electricity and magnetism was made complete with the discovery of electromagnetic induction by both Faraday and Joseph Henry in about 1831. In brief, a change in magnetic flux through a conducting circuit produces a current in the circuit. The observation that the induced current is in a direction to oppose the change that produces it, now known as Lenz's law, was formulated by a Russian-born physicist, Heinrich Friedrich Emil Lenz, in 1834. When the laws were put into mathematical form by Maxwell, the law of induction was generalized to include the production of electric force in space, independent of actual conducting circuits, but was otherwise unchanged. On the other hand, Ampère's law describing the magnetic effect of a current required amendment in order to be consistent with the conservation of charge (the total charge must remain constant) in the presence of changing electric fields, and Maxwell introduced the idea of "displacement current" to make the set of equations logically consistent. As a result, he found on combining the equations that he arrived at a wave equation, according to which transverse electric and magnetic disturbances were propagated with a velocity that could be calculated from electrical measurements. These measurements were available to Maxwell, having been made in 1856 by the German physicists Rudolph Hermann Arndt Kohlrausch and Wilhelm Eduard Weber, and his calculation gave him a result that was the same, within the limits of error, as the speed of light in vacuum. It was the coincidence of this value with the velocity of the waves predicted by his theory that convinced Maxwell of the electromagnetic nature of light. (M.Ph./Ht.F.)

Electromagnetic induction

The electromagnetic wave and field concept. Faraday introduced the concept of field and of field lines of force that exist outside material bodies. As he explained it, the region around and outside a magnet or an electric charge contains a field that describes at any location the force experienced by another small magnet or charge placed there. The lines of force around a magnet can be made visible by iron filings sprayed on a paper that is held over the magnet. The concept of field, specifying as it does a certain possible action or force at any location in space, was the key to understanding electromagnetic phenomena. It should be mentioned parenthetically that the field concept also plays (in varied forms) a pivotal role in modern theories of particles and forces.

Besides introducing this important concept of electric and magnetic field lines of force, Faraday had the extraordinary insight that electrical and magnetic actions are not transmitted instantaneously but after a certain lag in time, which increases with distance from the source. Moreover, he realized the connection between magnetism and light after observing that a substance such as glass can rotate the plane of polarization of light in the presence of a magnetic field. This remarkable phenomenon is known as the Faraday effect.

Faraday effect

As noted above, Maxwell formulated a quantitative theory that linked the fundamental phenomena of electricity and magnetism and that predicted electromagnetic waves propagating with a speed, which, as well as one could determine at that time, was identical with the speed of light. He concluded his paper "On the Physical Lines of Force" (1861–62) by saying that electricity may be disseminated through space with properties identical with those of light. In 1864 Maxwell wrote that the numerical factor linking the electrostatic and the magnetic units was very close to

the speed of light and that these results "show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to [his] electromagnetic laws."

What more was needed to convince the scientific community that the mystery of light was solved and the phenomena of electricity and magnetism were unified in a grand theory? Why did it take 25 more years for Maxwell's theory to be accepted? For one, there was little direct proof of the new theory. Furthermore, Maxwell not only had adopted a complicated formalism but also explained its various aspects by unusual mechanical concepts. Even though he stated that all such phrases are to be considered as illustrative and not as explanatory, the French mathematician Henri Poincaré remarked in 1899 that the "complicated structure" which Maxwell attributed to the ether "rendered his system strange and unattractive."

The ideas of Faraday and Maxwell that the field of force has a physical existence in space independent of material media were too new to be accepted without direct proof. On the Continent, particularly in Germany, matters were further complicated by the success of Carl Friedrich Gauss and Wilhelm Eduard Weber in developing a potential field theory for the phenomena of electrostatics and magnetostatics and their continuing effort to extend this formalism to electrodynamics.

Hertz's contributions

It is difficult in hindsight to appreciate the reluctance to accept the Faraday–Maxwell theory. The impasse was finally removed by Hertz's work. In 1884 Hertz derived Maxwell's theory by a new method and put its fundamental equations into their present-day form. In so doing, he clarified the equations, making the symmetry of electric and magnetic fields apparent. The German physicist Arnold Sommerfeld spoke for most of his learned colleagues when, after reading Hertz's paper, he remarked, "the shades fell from my eyes," and admitted that he understood electromagnetic theory for the first time. Four years later, Hertz made a second major contribution: he succeeded in generating electromagnetic radiation of radio and microwave frequencies, measuring their speed by a standing-wave method and proving that these waves have the properties of reflection, diffraction, refraction, and interference common to light. He showed that such electromagnetic waves can be polarized, that the electric and magnetic fields oscillate in directions that are mutually perpendicular and transverse to the direction of motion, and that their velocity is the same as the speed of light, as predicted by Maxwell's theory.

Hertz's ingenious experiments not only settled the theoretical misconceptions in favour of Maxwell's electromagnetic field theory but also opened the way for building transmitters, antennas, coaxial cables, and detectors for radio-frequency electromagnetic radiation. In 1896 Marconi received the first patent for wireless telegraphy, and in 1901 he achieved transatlantic radio communication.

The Faraday–Maxwell–Hertz theory of electromagnetic radiation, which is commonly referred to as Maxwell's theory, makes no reference to a medium in which the electromagnetic waves propagate. A wave of this kind is produced, for example, when a line of charges is moved back and forth along the line. Moving charges represent an electric current. In this back-and-forth motion, the current flows in one direction and then in another. As a consequence of this reversal of current direction, the magnetic field around the current (discovered by Ørsted and Ampère) has to reverse its direction. The time-varying magnetic field produces perpendicular to it a time-varying electric field, as discovered by Faraday (Faraday's law of induction). These time-varying electric and magnetic fields spread out from their source, the oscillating current, at the speed of light in free space. The oscillating current in this discussion is the oscillating current in a transmitting antenna, and the time-varying electric and magnetic fields that are perpendicular to one another propagate at the speed of light and constitute an electromagnetic wave. Its frequency is that of the oscillating charges in the antenna. Once generated, it is self-propagating because a time-varying electric field produces a time-varying magnetic field, and vice versa. Electromagnetic radiation travels through space by itself. The belief in the existence of an ether medium, however, was at the time of Maxwell as strong as at the time of Plato and Aristotle. It was impossible to visualize ether because contradictory properties had to be attributed to it in order to explain the phenomena known at any given time. In his article ETHER in the ninth edition of the *Encyclopædia Britannica*, Maxwell described the vast expanse of the substance, some of it possibly even inside the planets, carried along with them or passing through them as the "water of the sea passes through the meshes of a net when it is towed along by a boat."

If one believes in the ether, it is, of course, of fundamental importance to measure the speed of its motion or the effect of its motion on the speed of light. One does not know the absolute velocity of the ether, but as the Earth moves through its orbit around the Sun there should be a difference in ether velocity along and perpendicular to the Earth's motion equal to its speed. If such is the case, the velocity of light and of any other electromagnetic radiation along and perpendicular to the Earth's motion should, predicted Maxwell, differ by a fraction that is equal to the square of the ratio of the Earth's velocity to that of light. This fraction is one part in 100 million.

Michelson set out to measure this effect and, as noted above, designed for this purpose the interferometer sketched in Figure 4. If it is assumed that the interferometer is turned so that half beam A is oriented parallel to the Earth's motion and half beam B is perpendicular to it, then the idea of using this instrument for measuring the effect of the ether motion is best explained by Michelson's words to his children:

> Two beams of light race against each other, like two swimmers, one struggling upstream and back, while the other, covering the same distance, just crosses the river and returns. The second swimmer will always win, if there is any current in the river.

Michelson–Morley experiment

An improved version of the interferometer, in which each half beam traversed its path eight times before both were reunited for interference, was built in 1887 by Michelson in collaboration with Morley. A heavy sandstone slab holding the interferometer was floated on a pool of mercury to allow rotation without vibration. Michelson and Morley could not detect any difference in the two light velocities parallel and perpendicular to the Earth's motion to an accuracy of one part in four billion. This negative result did not, however, shatter the belief in the existence of an ether because the ether could possibly be dragged along with the Earth and thus be stationary around the Michelson–Morley apparatus. Hertz's formulation of Maxwell's theory made it clear that no medium of any sort was needed for the propagation of electromagnetic radiation. In spite of this, ether-drift experiments continued to be conducted until about the mid-1920s. All such tests confirmed Michelson's negative results, and scientists finally came to accept the idea that no ether medium was needed for electromagnetic radiation.

Speed of light. Much effort has been devoted to measuring the speed of light, beginning with the aforementioned work of Rømer in 1676. Rømer noticed that the orbital period of Jupiter's first moon, Io, is apparently slowed as the Earth and Jupiter move away from each other. The eclipses of Io occur later than expected when Jupiter is at its most remote position. This effect is understandable if light requires a finite time to reach the Earth from Jupiter. From this effect, Rømer calculated the time required for light to travel from the Sun to the Earth as 11 minutes. In 1728 James Bradley, an English astronomer, determined the speed of light from the apparent orbital motion of stars that is produced by the orbital motion of the Earth. He computed the time for light to reach the Earth from the Sun as eight minutes, 12 seconds. The first terrestrial measurements were made in 1849 by Fizeau and a year later by Foucault. Michelson improved on Foucault's method and obtained an accuracy of one part in 100,000.

Any measurement of velocity requires, however, a definition of the measure of length and of time. Current techniques allow a determination of the velocity of electromagnetic radiation to a substantially higher degree of precision than permitted by the unit of length that scien-

tists had applied earlier. In 1983 the value of the speed of light was fixed at exactly 299,792,458 metres per second, and this value was adopted as a new standard. As a consequence, the metre was redefined as the length of the path traveled by light in a vacuum over a time interval of 1/299,792,458 of a second. Furthermore, the second—the international unit of time—has been based on the frequency of electromagnetic radiation emitted by a cesium-133 atom.

DEVELOPMENT OF THE QUANTUM THEORY OF RADIATION

After a long struggle electromagnetic wave theory had triumphed. The Faraday–Maxwell–Hertz theory of electromagnetic radiation seemed to be able to explain all phenomena of light, electricity, and magnetism. The understanding of these phenomena enabled one to produce electromagnetic radiation of many different frequencies which had never been observed before and which opened a world of new opportunities. No one suspected that the conceptional foundations of physics were about to change again.

Radiation laws and Planck's light quanta. The quantum theory of absorption and emission of radiation announced in 1900 by Planck ushered in the era of modern physics. He proposed that all material systems can absorb or give off electromagnetic radiation only in "chunks" of energy, quanta E, and that these are proportional to the frequency of that radiation $E = h\nu$. (The constant of proportionality h is, as noted above, called Planck's constant.)

Planck was led to this radically new insight by trying to explain the puzzling observation of the amount of electromagnetic radiation emitted by a hot body and, in particular, the dependence of the intensity of this incandescent radiation on temperature and on frequency. The quantitative aspects of the incandescent radiation constitute the radiation laws.

The Austrian physicist Josef Stefan found in 1879 that the total radiation energy per unit time emitted by a heated surface per unit area increases as the fourth power of its absolute temperature T (Kelvin scale). This means that the Sun's surface, which is at $T = 6{,}000$ K, radiates per unit area $(6{,}000/300)^4 = 20^4 = 160{,}000$ times more electromagnetic energy than does the same area of the Earth's surface, which is taken to be $T = 300$ K. In 1889 another Austrian physicist, Ludwig Boltzmann, used the second law of thermodynamics to derive this temperature dependence for an ideal substance that emits and absorbs all frequencies. Such an object that absorbs light of all colours looks black, and so was called a blackbody. The Stefan–Boltzmann law is written in quantitative form $W = \sigma T^4$, where W is the radiant energy emitted per second and per unit area and the constant of proportionality is $\sigma = 0.136$ calories per metre^2-second-K^4.

Stefan–Boltzmann law

The wavelength or frequency distribution of blackbody radiation was studied in the 1890s by Wilhelm Wien of Germany. It was his idea to use as a good approximation for the ideal blackbody an oven with a small hole. Any radiation that enters the small hole is scattered and reflected from the inner walls of the oven so often that nearly all incoming radiation is absorbed and the chance of some of it finding its way out of the hole again can be made exceedingly small. The radiation coming out of this hole is then very close to the equilibrium blackbody electromagnetic radiation corresponding to the oven temperature. Wien found that the radiative energy dW per wavelength interval $d\lambda$ has a maximum at a certain wavelength λ_m, and that the maximum shifts to shorter wavelengths as the temperature T is increased, as illustrated in Figure 9. He found that the product $\lambda_m T$ is an absolute constant: $\lambda_m T = 0.2898$ centimetre-degree Kelvin.

Wien's law of the shift of the radiative power maximum to higher frequencies as the temperature is raised expresses in a quantitative form commonplace observations. Warm objects emit infrared radiation, which is felt by the skin; near $T = 950$ K a dull red glow can be observed; and the colour brightens to orange and yellow as the temperature is raised. The tungsten filament of a light bulb is $T = 2{,}500$ K hot and emits bright light, yet the peak of its spectrum is still in the infrared according to Wien's law.

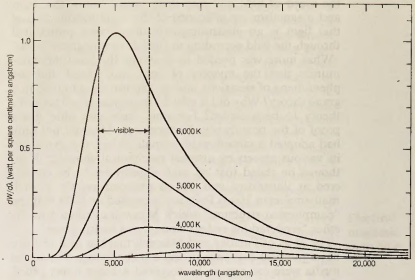

Figure 9: Electromagnetic energy dW emitted per unit area and per second into a wavelength interval, $d\lambda$ = one angstrom, by a blackbody at various temperatures between 3,000 and 6,000 K as a function of wavelength. The range of visible light is between the vertical dashed lines.

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The peak shifts to the visible yellow when the temperature is $T = 6{,}000$ K, like that of the Sun's surface.

It was the shape of Wien's radiative energy distribution as a function of frequency that Planck tried to understand. The decrease of the radiation output at low frequency had already been explained by Lord Rayleigh (John William Strutt) in terms of the decrease, with lowering frequency, in the number of modes of electromagnetic radiation per frequency interval. Rayleigh assumed that all possible frequency modes could radiate with equal probability, following the principle of equipartition of energy. Since the number of frequency modes per frequency interval continues to increase without limit with the square of the frequency, Rayleigh's formula predicted an ever-increasing amount of radiation of higher frequencies instead of the observed maximum and subsequent fall in radiative power. A possible way out of this dilemma was to deny the high-frequency modes an equal chance to radiate. To achieve this, Planck postulated that the radiators or oscillators can only emit electromagnetic radiation in finite amounts of energy of size $E = h\nu$. At a given temperature T, there is then not enough thermal energy available to create and emit many large radiation quanta $h\nu$. More large energy quanta $h\nu$ can be emitted, however, when the temperature is raised. Quantitatively the probability of emitting at temperature T an electromagnetic energy quantum $h\nu$ is

$$\frac{1}{e^{h\nu/kT} - 1},$$

where k is Boltzmann's constant, well known from thermodynamics. With $c = \lambda\nu$, Planck's radiation law then becomes

Planck's radiation law

$$dW = \frac{8\pi c h \lambda^{-5} d\lambda}{e^{hc/\lambda kT} - 1}.$$

This is in superb agreement with Wien's experimental results when the value of h is properly chosen to fit the results. It should be pointed out that Planck's quantization refers to the oscillators of the blackbody or of heated substances. These oscillators of frequency ν are incapable of absorbing or emitting electromagnetic radiation except in energy chunks of size $h\nu$. To explain quantized absorption and emission of radiation, it seemed sufficient to quantize only the energy levels of mechanical systems. Planck did not mean to say that electromagnetic radiation itself is quantized, or as Einstein later put it, "The sale of beer in pint bottles does not imply that beer exists only in indivisible pint portions." The idea that electromagnetic radiation itself is quantized was proposed by Einstein in 1905, as described in the subsequent section.

Photoelectric effect. Hertz discovered the photoelectric effect (1887) quite by accident while generating elec-

tromagnetic waves and observing their propagation. His transmitter and receiver were induction coils with spark gaps. He measured the electromagnetic field strength by the maximum length of the spark of his detector. In order to observe this more accurately, he occasionally enclosed the spark gap of the receiver in a dark case. In doing so, he observed that the spark was always smaller with the case than without it. He concluded correctly that the light from the transmitter spark affected the electrical arcing of the receiver. He used a quartz prism to disperse the light of the transmitter spark and found that the ultraviolet part of the light spectrum was responsible for enhancing the receiver spark. Hertz took this discovery seriously because the only other effect of light on electrical phenomena known at that time was the increase in electrical conductance of the element selenium with light exposure.

A year after Hertz's discovery, it became clear that ultraviolet radiation caused the emission of negatively charged particles from solid surfaces. Thomson's discovery of electrons (1897) and his ensuing measurement of the ratio m/e (the ratio of mass to charge) finally made it possible to identify the negative particles emitted in the photoelectric effect with electrons. This was accomplished in 1899 by J.J. Thomson and independently by Philipp Lenard, one of Hertz's students. Lenard discovered that for a given frequency of ultraviolet radiation the maximum kinetic energy of the emitted electrons depends on the metal used rather than on the intensity of the ultraviolet light. The light intensity increases the number but not the energy of emitted electrons. Moreover, he found that for each metal there is a minimum light frequency that is needed to induce the emission of electrons. Light of a frequency lower than this minimum frequency has no effect regardless of its intensity.

In 1905 Einstein published an article entitled "On a Heuristic Point of View about the Creation and Conversion of Light." Here he deduced that electromagnetic radiation itself consists of "particles" of energy $h\nu$. He arrived at this conclusion by using a simple theoretical argument comparing the change in entropy of an ideal gas caused by an isothermal change in volume with the change in entropy of an equivalent volume change for electromagnetic radiation in accordance with Wien's or Planck's radiation law. This derivation and comparison made no references to substances and oscillators. At the end of this paper, Einstein concluded that if electromagnetic radiation is quantized, the absorption processes are thus quantized too, yielding an elegant explanation of the threshold energies and the intensity dependence of the photoelectric effect. He then predicted that the kinetic energy of the electrons emitted in the photoelectric effect increases with light frequency ν proportional to $h\nu - P$, where P is "the amount of work that the electron must produce on leaving the body." This quantity P, now called work function, depends on the kind of solid used, as discovered by Lenard.

Reaction to Einstein's idea of light quanta

Einstein's path-breaking idea of light quanta was not widely accepted by his peers. Planck himself stated as late as 1913 in his recommendation for admitting Einstein to the Prussian Academy of Sciences "the fact that he [Einstein] may occasionally have missed the mark in his speculations, as, for example, with his hypothesis of light quanta, ought not to be held too much against him, for it is impossible to introduce new ideas, even in the exact sciences, without taking risks." In order to explain a quantized absorption and emission of radiation by matter, it seemed sufficient to quantize the possible energy states in matter. The resistance against quantizing the energies of electromagnetic radiation itself is understandable in view of the incredible success of Maxwell's theory of electromagnetic radiation and the overwhelming evidence of the wave nature of this radiation. Moreover, a formal similarity of two theoretical expressions, in Einstein's 1905 paper, of the entropy of an ideal gas and the entropy of electromagnetic radiation was deemed insufficient evidence for a real correspondence.

Einstein's prediction of the linear increase of the kinetic energy of photoemitted electrons with frequency of light, $h\nu - P$, was verified by Arthur Llewelyn Hughes, Owen Williams Richardson, and Karl Taylor Compton in 1912. In 1916 Robert Andrews Millikan measured both the frequency of the light and the kinetic energy of the electron emitted by the photoelectric effect and obtained a value for Planck's constant h in close agreement with the value that had been arrived at by fitting Planck's radiation law to the blackbody spectrum obtained by Wien.

Compton effect. Convincing evidence of the particle nature of electromagnetic radiation was found in 1922 by the American physicist Arthur Holly Compton. While investigating the scattering of X rays, he observed that such rays lose some of their energy in the scattering process and emerge with slightly decreased frequency. This energy loss increases with the scattering angle, θ, measured from the direction of an unscattered X ray. This so-called Compton effect can be explained, according to classical mechanics, as an elastic collision of two particles comparable to the collision of two billiard balls. In this case, an X-ray photon of energy $h\nu$ and momentum $h\nu/c$ collides with an electron at rest. The recoiling electron was observed and measured by Compton and Alfred W. Simon in a Wilson cloud chamber. If one calculates the result of such an elastic collision using the relativistic formulas for the energy and momentum of the scattered electron, one finds that the wavelength of an X ray after (λ') and before (λ) the scattering event differ by $\lambda' - \lambda = (h/mc)(1 - \cos\theta)$. Here m is the rest mass of the electron and h/mc is called Compton wavelength. It has the value 0.0243 angstrom. The energy $h\nu$ of a photon of this wavelength is equal to the rest mass energy mc^2 of an electron. One might argue that electrons in atoms are not at rest, but their kinetic energy is very small compared to that of energetic X rays and can be disregarded in deriving Compton's equation.

Resonance absorption and recoil. During the mid-1800s the German physicist Gustav Robert Kirchhoff observed that atoms and molecules emit and absorb electromagnetic radiation at characteristic frequencies and that the emission and absorption frequencies are the same for a given substance. Such resonance absorption should, strictly speaking, not occur if one applies the photon picture due to the following argument. Since energy and momentum have to be conserved in the emission process, the atom recoils to the left as the photon is emitted to the right, just as a cannon recoils backward when a shot is fired. Because the recoiling atom carries off some kinetic recoil energy E_R, the emitted photon energy is less than the energy difference of the atomic energy states by the amount E_R. When a photon is absorbed by an atom, the momentum of the photon is likewise transmitted to the atom, thereby giving it a kinetic recoil energy E_R. The absorbing photon must therefore supply not only the energy difference of the atomic energy states but the additional amount E_R as well. Accordingly, resonance absorption should not occur because the emitted photon is missing $2E_R$ to accomplish it.

Nevertheless, ever since Kirchhoff's finding, investigators have observed resonance absorption for electronic transitions in atoms and molecules. This is because for visible light the recoil energy E_R is very small compared with the natural energy uncertainty of atomic emission and absorption processes. The situation is, however, quite different for the emission and absorption of gamma-ray photons by nuclei. The recoil energy E_R is more than 10,000 times as large for gamma-ray photons as for photons of visible light, and the nuclear energy transitions are much more sharply defined because their lifetime can be one million times longer than for electronic energy transitions. The particle nature of photons therefore prevents resonance absorption of gamma-ray photons by free nuclei.

Recoil-free gamma-ray resonance absorption

In 1958 the German physicist Rudolf Ludwig Mössbauer discovered that recoilless gamma-ray resonance absorption is, nevertheless, possible if the emitting as well as the absorbing nuclei are embedded in a solid. In this case, there is a strong probability that the recoil momentum during absorption and emission of the gamma photon is taken up by the whole solid (or more precisely by its entire lattice). This then reduces the recoil energy to nearly zero and thus allows resonance absorption to occur even for gamma rays.

Wave–particle duality. How can electromagnetic radi-

ation behave like a particle in some cases while exhibiting wavelike properties that produce the interference and diffraction phenomena in others? This paradoxical behaviour came to be known as the wave–particle duality. Bohr rejected the idea of light quanta, and he searched for ways to explain the Compton effect and the photoelectric effect by arguing that the momentum and energy conservation laws need to be satisfied only statistically in the time average. In 1923 he stated that the hypothesis of light quanta excludes, in principle, the possibility of a rational definition of the concepts of frequency and wavelength that are essential for explaining interference.

The following year, the conceptual foundations of physics were shaken by the French physicist Louis-Victor de Broglie, who suggested in his doctoral dissertation that the wave–particle duality applies not only to light but to a particle as well. De Broglie proposed that any object has wavelike properties. In particular, he showed that the orbits and energies of the hydrogen atom, as described by Bohr's atomic model, correspond to the condition that the circumference of any orbit precisely matches an integral number of wavelengths λ of the matter waves of electrons. Any particle such as an electron moving with a momentum p has, according to de Broglie, a wavelength $\lambda = h/p$. This idea required a conceptual revolution of mechanics, which led to the wave and quantum mechanics of Erwin Schrödinger, Werner Heisenberg, and Max Born.

Verification of de Broglie's idea of the wavelike behaviour of particles

De Broglie's idea of the wavelike behaviour of particles was quickly verified experimentally. In 1927 Clinton Joseph Davisson and Lester Germer of the United States observed diffraction and hence interference of electron waves by the regular arrangement of atoms in a crystal of nickel. That same year S. Kikuchi of Japan obtained an electron diffraction pattern by shooting electrons with an energy of 68 keV through a thin mica plate and recording the resultant diffraction pattern on a photographic plate. The observed pattern corresponded to electron waves having the wavelength predicted by de Broglie. The diffraction effects of helium atoms were found in 1930, and neutron diffraction has today become an indispensable tool for determining the magnetic and atomic structure of materials.

The interference pattern that results when a radiation front hits two slits in an opaque screen is often cited to explain the conceptual difficulty of the wave–particle duality. Consider an opaque screen with two openings A and B, called double slit, and a photographic plate or a projection screen, as shown in Figure 10. A parallel wave with a wavelength λ passing through the double slit will produce the intensity pattern on the plate or screen as shown at the right of the figure. The intensity is greatest at the centre. It falls to zero at all locations x_0, where the distances to the openings A and B differ by odd-number multiples of a half wavelength, as, for instance, $\lambda/2$, $3\lambda/2$, and $5\lambda/2$. The condition for such destructive interference is the same as for Michelson's interferometer illustrated in Figure 4. Whereas a half-transparent mirror in Figure 4 divides the amplitude of each wave train in half, the division in Figure 10 through openings A and B is spatial. The latter is called division of wave front. Constructive interference or intensity maxima are observed on the screen at all positions whose distances from A and B differ by zero or an integer multiple of λ. This is the wave interpretation of the observed double-slit interference pattern.

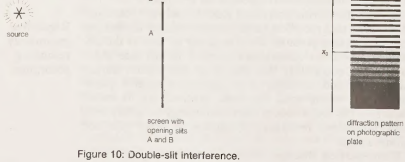

Figure 10: Double-slit interference.

The description of photons is necessarily different because a particle can obviously only pass through opening A or alternatively through opening B. Yet, no interference pattern is observed when either A or B is closed. Both A and B must be open simultaneously. It was thought for a time that one photon passing through A might interfere with another photon passing through B. That possibility was ruled out after the British physicist Geoffrey Taylor demonstrated in 1909 that the same interference pattern can be recorded on a photographic plate even when the light intensity is so feeble that only one photon is present in the apparatus at any one time.

Another attempt to understand the dual nature of electromagnetic radiation was to identify the photon with a wave train whose length is equal to its coherence length $c\tau$, where τ is the coherence time, or the lifetime of an atomic transition from a higher to a lower internal atomic energy state, and c is the light velocity. This is the same as envisioning the photon to be an elongated wave packet, or "needle radiation." Again, the term "photon" had a different meaning for different scientists, and wave nature and quantum structure remained incompatible. It was time to find a theory of electromagnetic radiation that would fuse the wave theory and the particle theory. Such a fusion was accomplished by quantum electrodynamics (QED).

Quantum electrodynamics. Among the most convincing phenomena that demonstrate the quantum nature of light are the following. As the intensity of light is dimmed further and further, one can see individual quanta being registered in light detectors. If the eyes were about 10 times more sensitive, one would perceive the individual light pulses of fainter and fainter light sources as fewer and fewer flashes of equal intensity. Moreover, a movie has been made of the buildup of a two-slit interference pattern by individual photons, such as shown in Figure 10. Photons are particles, but they behave differently from ordinary particles like billiard balls. The rules of their behaviour and their interaction with electrons and other charged particles, as well as the interactions of charged particles with one another, constitute QED.

Subject of QED

Photons are created by perturbances in the motions of electrons and other charged particles; and, in reverse, photons can disappear and thereby create a pair of oppositely charged particles, usually a particle and its antiparticle (*e.g.*, an electron and a positron). A description of this intimate interaction between charged particles and electromagnetic radiation requires a theory that includes both quantum mechanics and special relativity. The foundations of such a theory, known as relativistic quantum mechanics, were laid beginning in 1929 by Paul A.M. Dirac, Heisenberg, and Wolfgang Pauli.

The discussion that follows explains in brief the principal conceptual elements of QED. Further information on the subject can be found in SUBATOMIC PARTICLES: *The development of modern theory;* and MECHANICS: *Quantum mechanics.*

Many phenomena in nature do not depend on the reference scale of scientific measurements. For instance, in electromagnetism the difference in electrical potentials is relevant but not its absolute magnitude. During the 1920s, even before the emergence of quantum mechanics, the German physicist Hermann Weyl discussed the problem of constructing physical theories that are independent of certain reference bases or absolute magnitudes of certain parameters not only locally but everywhere in space. He called this property "Eich Invarianz," which is the conceptual origin of the term "gauge invariance" that plays a crucial role in all modern quantum field theories.

In quantum mechanics all observable quantities are calculated from so-called wave functions, which are complex mathematical functions that include a phase factor. The absolute magnitude of this phase is irrelevant for the observable quantities calculated from these wave functions; hence, the theory describing, for example, the motion of an electron should be the same when the phase of its wave function is changed everywhere in space. This requirement of phase invariance, or gauge invariance, is

Gauge invariance

equivalent to demanding that the total charge is conserved and does not disappear in physical processes or interactions. Experimentally one does indeed observe that charge is conserved in nature.

It turns out that a relativistic quantum theory of charged particles can be made gauge invariant if the interaction is mediated by a massless and chargeless entity which has all the properties of photons. Coulomb's law of the force between charged particles can be derived from this theory, and the photon can be viewed as a "messenger" particle that conveys the electromagnetic force between charged particles of matter. In this theory, Maxwell's equations for electric and magnetic fields are quantized.

The range of a force produced by a particle with nonzero mass is its Compton wavelength h/mc, which for electrons is about 2×10^{-10} centimetre. Since this length is large compared with distances over which stronger nuclear forces act, QED is a very precise theory for electrons.

Despite the conceptual elegance of the QED theory, it proved difficult to calculate the outcome of specific physical situations through its application. Richard P. Feynman and, independently, Julian S. Schwinger and Freeman Dyson of the United States and Tomonaga Shin'ichirō of Japan showed in 1948 that one could calculate the effects of the interactions as a power series in which the coupling constant is called the fine structure constant and has a value close to $^1/_{137}$. A serious practical difficulty arose when each term in the series, which had to be summed to obtain the value of an observed quantity, turned out to be infinitely large. In short, the results of the calculations were meaningless. It was eventually found, however, that these divergences could be avoided by introducing "renormalized" couplings and particle masses, an idea conceived by the Dutch physicist Hendrik A. Kramers. Just as a ship moving through water has an enhanced mass due to the fluid that it drags along, so will an electron dragging along and interacting with its own field have a different mass and charge than it would without it. By adding appropriate electromagnetic components to the bare mass and charge—that is, by using renormalized quantities—the disturbing infinities could be removed from the theory. Using this method of renormalization and the perturbation theory, Feynman developed an elegant form for calculating the likelihood of observing processes that are related to the interaction of electromagnetic radiation with matter to any desired degree of accuracy. For example, the passage of an electron or a photon through the double slit illustrated in Figure 10 will, in this QED formalism, produce the observed interference pattern on a photographic plate because of the superposition of all the possible paths these particles can take through the slits.

The success of unifying electricity, magnetism, and light into one theory of electromagnetism and then with the interaction of charged particles into the theory of quantum electrodynamics suggests the possibility of understanding all the forces in nature (gravitational, electromagnetic, weak nuclear, and strong nuclear) as manifestations of a grand unified theory (GUT). The first step in this direction was taken during the 1960s by Abdus Salam, Steven Weinberg, and Sheldon Glashow, who formulated the electroweak theory, which combines the electromagnetic force and the weak nuclear force. This theory predicted that the weak nuclear force is transmitted between particles of matter by three messenger particles designated W^+, W^-, and Z, much in the way that the electromagnetic force is conveyed by photons. The three new particles were discovered in 1983 during experiments at the European Organization for Nuclear Research (CERN), a large accelerator laboratory near Geneva. This triumph for the electroweak theory represented another stepping stone toward a deeper understanding of the forces and interactions that yield the multitude of physical phenomena in the universe. GUT

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Electronic Games

In the broadest definition, electronic games encompass any type of interactive game operated by computer circuitry. The machines, or "platforms," on which electronic games are played include general-purpose shared and personal computers, arcade consoles, video consoles connected to home television sets, and handheld game machines. The term video game can be used to represent the totality of these formats, or it can refer more specifically only to games played on devices with video displays: television and arcade consoles.

FROM CHESS TO *SPACEWAR!* TO *PONG*

The idea of playing games on computers is almost as old as the computer itself. Initially, the payoffs expected from this activity were closely related to the study of computation. For example, the mathematician and engineer Claude Shannon proposed in 1950 that computers could be programmed to play chess, and he questioned whether this would mean that a computer could think. Shannon's proposal stimulated decades of research on chess- and checkers-playing programs, generally by computer scientists working in the field of artificial intelligence.

Many computer games grew out of university and industrial computer laboratories, often as technology demonstrations or "after hours" amusements of computer scientists. For example, in 1958 William A. Higinbotham of the Brookhaven National Laboratory in New York used an analog computer, control boxes, and an oscilloscope to create *Tennis for Two* as part of a public display for visitors to the laboratory. Only a few years later, Steve Russell, Alan Kotok, J. Martin Graetz, and others created *Spacewar!* (1962) at the Massachusetts Institute of Technology (MIT). This game began as a demonstration program to show off the PDP-1 minicomputer donated by Digital Equipment Corporation (DEC) to MIT and the new Precision CRT Display Type 30 attached to it. This new technology appealed to the "hacker" culture of the Tech Model Railroad Club on campus, and its authors were members of this group. They wrote software and built control boxes that gave players the ability to move spaceships depicted on accurate star maps, maneuvering about and firing space torpedoes in a competitive match.

With the widespread adoption of PDPs on other campuses and laboratories in the 1960s and '70s, *Spacewar!* was soon ubiquitous. One such institution was the University of Utah, home of a strong program in computer graphics and an electrical engineering student named Nolan Bushnell. After graduating, Bushnell moved to Silicon Valley to work for the Ampex Corporation. Bushnell had worked at an amusement park during college, and, after playing *Spacewar!*, he dreamed of filling entertainment arcades with such computer games. Together with one of his coworkers at Ampex, Ted Dabney, Bushnell designed *Computer Space* (1971), a coin-operated version of *Spacewar!* set in a wildly futuristic arcade cabinet. Although the game—manufactured and marketed by Nutting Associates, a vendor of coin-operated arcades—was a commercial failure, it established a design and general technical configuration for arcade consoles.

Atari Corporation

In 1972 Bushnell, Dabney, and Al Alcorn, another Ampex alumnus, founded the Atari Corporation. Bushnell asked Alcorn to design a simple game based on Ping-Pong, explaining by way of inspiration that Atari had received a contract to make it. While there was in fact no such contract, Alcorn was adept at television electronics and produced a simple and addictive game, which they named *Pong*. Unable to interest manufacturers of pinball games in this prototype, Bushnell and Alcorn installed it in a local bar, where it became an immediate success as a coin-operated game. After clearing a legal obstacle posed by the Magnavox Corporation's hold on the patent for video games (see below), Atari geared up to manufacture arcade consoles in volume, creating a new industry while also attracting competitors.

EARLY HOME VIDEO CONSOLES

After computers and arcades, the third inspiration for early electronic games was television. Ralph Baer, a television engineer and manager at the military electronics firm of Sanders Associates (now part of BAE Systems), began in the late 1960s to develop technology and design games that could be played on television sets. In 1966 Baer designed circuitry to display and control moving dots on a television screen, leading to a simple chase game that he called *Fox and Hounds*. With this success in hand, Baer secured permission and funding from Sanders management to assemble a small group, the TV Game Project. Within a year several promising game designs had been demonstrated, and Baer's group experimented with ways of delivering games to households by means such as cable television. In 1968 they completed the Brown Box, a solid-state prototype for a video game console. Three years later Baer was granted a U.S. patent for a "television gaming apparatus." Magnavox acquired the rights soon thereafter, leading in 1972 to production of the first home video console, the Magnavox Odyssey.

Magnavox Odyssey

The success of *Pong* as a coin-operated game led a number of companies, including Atari itself, to forge ahead with home versions and imitations of the game. Seeking to expand its coin-operated arcade business, Atari reached agreement with Sears, Roebuck and Company to manufacture and distribute the home version of *Pong*. Its success intensified the already brutal competition in this market. The Atari 2600 VCS (Video Computer System), released in 1977, and other new consoles followed the Odyssey model by offering multiple games. These systems were programmable in the sense that different game cartridges could be inserted into special slots—a technical step that encouraged the separation of game development from hardware design. Activision, founded in 1979 by four former Atari game designers, was the first company exclusively focused on game software. By 1983, however, a flood of poorly designed game titles for the leading home consoles led to a consumer backlash and a sharp decline in the video console industry, shifting momentum back to computer-based games.

INTERACTIVE FICTION

Games developed for the first arcade and home consoles emphasized simplicity and action. This was partly out of necessity, due to the limitations of rudimentary display technologies, microprocessors, and other components and to the limited memory available for programs. (These traits also reflected the goal of creating games that would quickly swallow as many coins as possible.) Still, while the designs of games such as Atari's *Breakout* (1976) or Taito's *Space Invaders* (1978) were elegantly streamlined, these arcade hits generally offered little in terms of strategic depth, narrative, or simulation value. By the mid-1970s, however, several computer games challenged these restrictions. These games relied on text, networking, or other capabilities available on computers in academic laboratories.

One of the first was *Hunt the Wumpus*, which appeared in several versions for different systems. Kenneth Thompson, a researcher at Bell Laboratories, wrote one version in C for the UNIX operating system, which he had codeveloped; Gregory Yob wrote another in BASIC that was distributed widely through listings in early computer game magazines. Both versions were probably written in 1972. *Hunt the Wumpus* and games like it introduced the notion of defining a virtual space. Players explored this space by inputting simple text commands—such as room num-

bers or coordinates—from their keyboards. Such games could be easily shared, modified, and extended by programmers, resulting in a great variety of similar games. Players enjoyed considerable freedom of navigation in exploring the caves, dungeons, and castles typical of this genre.

The defining "text adventure" was *Adventure*, written by Will Crowther, probably in 1975, if not earlier. Crowther combined his experiences exploring Kentucky's Mammoth and Flint Ridge caves and playing *Dungeons and Dragons*-style role-playing games with fantasy themes reminiscent of J.R.R. Tolkien's *Lord of the Rings*. Written in FORTRAN for the PDP-10 computer, *Adventure* became the prototype for an entirely new category of games, usually called "interactive fiction," that boasted a new narrative structure. Such games shaped the player's experience with descriptions of rooms, characters, and items and a story that evolved in response to the player's choices. In *Adventure* this meant wandering through a dungeon to collect items and defeat monsters, but later titles featured more elaborate narratives. In 1976 Don Woods of the Stanford Artificial Intelligence Laboratory came across a copy of the source code for *Adventure* and carefully revised the game, adding new elements that increased its popularity. This version and its variants were widely distributed by users of DEC minicomputers. By the late 1970s, home computers and video game consoles also made commercial distribution of these games possible.

Interactive fiction

PERSONAL COMPUTER GAMES

By the late 1970s, electronic games could be designed not only for large, university-based shared computers, video consoles, and arcade machines but also for the new breed of home computers equipped with their own general-purpose microprocessors. Apple Computer Inc.'s Apple II (1977) and the IBM Personal Computer (1981) featured colour graphics, flexible storage capacity, and a variety of input devices. The Atari 800 (1979) and Commodore Business Machines' Commodore 64 (1982) offered similar features, but they also retained cartridge slots for console-style games. Game designers took advantage of the greater flexibility of computers to explore new game genres, often inspired by complex paper-and-pencil role-playing games such as *Dungeons and Dragons*, various board games, and Crowther's *Adventure*. Interactive fiction was a particularly successful format on personal computers. Infocom, perhaps the most successful computer game company of the early 1980s, adapted this style of game to a variety of literary formats, such as science fiction and mysteries. Infocom began with the popular *Zork* series, inspired directly by *Adventure*. Infocom games disdained graphics, relying on methods that allowed for more varied player input and story building and incorporating techniques such as language parsing and database programming learned by its founders at MIT to stimulate the player's imagination.

Other games—such as the *King's Quest* series by Sierra On-Line (1983), military simulations and role-playing games published by Strategic Simulations Incorporated (founded in 1979), Richard Garriott's *Akalabeth/Ultima* series (1979), and the sports and multimedia titles of Electronic Arts (founded in 1982)—extended the simulation and storytelling capacity of computer games. Networked games added a social dimension. *Empire* had been developed as part of the PLATO (Programmed Logic for Automatic Teaching Operations) Project at the University of Illinois during the early 1970s, and the possibilities of social interaction and networked-based graphics were thoroughly explored as part of this project and the games that resulted from it. *MUD* (Multi User Dungeon), developed in 1979 by Roy Trubshaw and Richard Bartle at the University of Essex, England, combined interactive fiction, role-playing, programming, and dial-up modem access to a shared computer. It inspired dozens of popular multiplayer games, known collectively as MUDs, that placed players in a virtual world that functioned on the basis of social interaction as much as structured game play. Hundreds of themed multiplayer MUDs were written during the 1980s and early '90s.

MUDs

THE RETURN OF VIDEO CONSOLES

Two Japanese manufacturers of coin-operated video games, the Nintendo Co., Ltd., and Sega Enterprises Ltd., introduced a new generation of video consoles, the Nintendo Entertainment System (NES; 1985) and the Sega Genesis (1989), with graphics that equaled or exceeded the capabilities of personal computers. More important, Nintendo introduced battery-powered storage cartridges that enabled players to save games in progress. Games such as Nintendo's *Super Mario Brothers* (1985) and *The Legend of Zelda* (1987), as well as Squaresoft's *Final Fantasy* series (1987; originally for Nintendo only), fully exploited the ability to save games in progress; they used it to provide deeper game experiences, flexible character development, and complex interactive environments. These qualities encouraged comparisons between video games and other narrative media such as cinema. In 1989 Nintendo extended its business success with the introduction of Game Boy, a handheld game system with a small monochrome display. It was not the first portable game player—Nintendo had marketed the small Game and Watch player since 1980—but it offered a new puzzle game, Alexey Pajitnov's *Tetris* (1989), an international best-seller that was ideally suited to the new device. More units of Game Boy, continued by the Game Boy Advance in 2001, have been sold than any other game device.

Game Boy

The next generation of video game consoles, including the Sony Corporation's Playstation 2 (2000), Nintendo's GameCube (2001), and the Microsoft Corporation's Xbox (2001), has been defined primarily by superior technology, especially graphics, though a more important trend may be the increasing convergence of these consoles with the networking and storage capacities of personal computers.

NETWORKED GAMES AND VIRTUAL WORLDS

During the 1990s, computer game designers exploited three-dimensional graphics, faster microprocessors, networking, handheld and wireless game devices, and the Internet to develop new genres for video consoles, personal computers, and networked environments. These included first-person "shooters"—action games in which the environment is seen from the player's view—such as id Software's *Wolfenstein 3-D* (1991), *DOOM* (1993), and *Quake* (1996); sports games such as Electronic Arts' *Madden Football* series (1989), based on motion-capture systems and artificial intelligence; and massively multiplayer games such as *Ultima Online* (1997) and *Everquest* (1998), combining traits of MUDs with graphical role-playing games to allow thousands of subscribers to create "avatars" (that is, representative icons or animated computer characters) and to explore "persistent" virtual worlds.

Today communities of game players organize themselves around multiplayer teams (or "clans"), Web sites devoted to specific games, and independent modifications (or "mods") of published games. These groups share common interests in computer game titles, using the Internet, broadband connections, LAN (local area network) parties, and other applications of networking technology in ways that increasingly merge in-game and out-of-game social experiences. For titles such as *The Sims* (2000) and *Half-Life: Counterstrike* (2000), this overlapping of virtual game worlds, in which multiplayer games are played, and virtual game communities, in which players socialize, is extending the range of player involvement while challenging game publishers to develop new forms of content.

Sales of computer and video games, including hardware and accessories, exceeded $10 billion in 2001 in the United States alone; in comparison, box office receipts for the American movie industry were about $8.35 billion. The publishers of the popular multiplayer game *Half-Life: Counterstrike*, reported some 3.4 billion player-minutes per month in mid-2002, exceeding viewership for even the highest-rated American television shows.

BREAKTHROUGH GAMES

Zork. Will Crowther's *Adventure (c.* 1975) was the prototype for text-based computer games organized as interactive stories, but in 1977 several students at the Massachusetts Institute of Technology (MIT) decided that

they could write more sophisticated interactive fiction by abandoning FORTRAN, the programming language used for *Adventure*, in favour of MDL. MDL was a descendant of LISP, a language that grew out of research in artificial intelligence. The characteristics of MDL enabled the students to build a database of objects in their game that greatly simplified the construction of rooms and game items—of which there were roughly 400 in all. The game was given the nonsense name *Zork*.

Practically any computer science student at a major American university could play the game by logging in to MIT over ARPANET (the precursor to the Internet), and *Zork* quickly gained cult status. In 1979 *Zork*'s programmers decided to form their own company, Infocom, and create a version of the game for personal computers (PCs). In particular, *Zork* illustrates Infocom's success in programming a language parser that could "understand" about 900 words and 70 actions.

Pac-Man. In 1980 the Japanese arcade game manufacturer Namco Limited introduced the world to *Pac-Man*. The lead designer was Iwatani Tohru, who intended to create a game that did not emphasize violence. By paying careful attention to themes, design, and colours, Iwatani hoped that Namco could market an arcade game that would appeal to females. The game concept was therefore inspired by food and eating, as opposed to the shooting of space aliens and other foes that prevailed in most arcade games of the time. Instead, players manoeuvered through a simple maze with a joystick, devouring coloured dots until all were gone, thereby completing a level and moving on to the next maze. In Japanese slang, *paku paku* describes the snapping of a mouth open and shut, and thus the central character, resembling a small pizza with a slice cut out for the mouth, was given the name *Pac-Man*. The game was made challenging by a group of four "ghosts" on each level that tried to catch and consume Pac-Man; the roles of predator and prey were temporarily reversed when Pac-Man ate special "power pills" placed in the maze.

Female players

Pac-Man quickly became an international sensation, with more than 100,000 consoles sold in the United States alone, easily making it the most successful arcade game in history. With its innovative design, *Pac-Man* had a greater impact on popular culture than any other video game. Guides to playing *Pac-Man* emerged on best-seller lists in the United States, soon followed by popular songs, a cartoon television series, merchandise, and magazine articles, as well as countless versions and imitations of the game for every electronic gaming platform.

The Legend of Zelda. When Nintendo released *The Legend of Zelda* for the Japanese market in 1986, it marked a new era in the culture, technology, and business of video games. The game's designer, Miyamoto Shigeru, was already a star, having produced *Donkey Kong* and the *Mario Brothers* series. Now he wanted to push further the concept of open-ended game play by giving players a large but unified world in which they could discover their own path for the development of the main character, named Link. Miyamoto's design exploited the improvements in Nintendo's graphics-processing chip, and the provision of battery-powered backup storage in Nintendo's new game cartridges allowed players to save their progress, thus making extended story lines more practical. The game interface also featured new elements, such as screens that were activated to manage the hero's items or abilities—a technique similar to the pull-down menus then beginning to appear in business software. These innovations gave players freedom to navigate through a fully two-dimensional world (viewed from the top down) as Link's personality evolved through his efforts to defeat the evil Ganon and rescue princess Zelda. Moreover, Miyamoto paid careful attention to the pacing and complexity of the game, ensuring that players would improve their skills as Link progressed to more difficult challenges. Success in *The Legend of Zelda* was measured by playing the game to completion over multiple sessions lasting perhaps dozens of hours, rather than scoring as many points as possible in a single session. Miyamoto thus raised expectations for greater narrative scope and more compelling game mechanics.

Game menus

DOOM. The appearance of *DOOM* in December 1993 changed the direction of almost every aspect of computer games, from graphics and networking technology to styles of play, notions of authorship, and public scrutiny of game content. The authors of *DOOM* were a group of programmers, led by John Romero and John Carmack, formed in Texas to create monthly games as employees of *Softdisk* magazine. While at *Softdisk* the group also produced shareware games for Apogee Software, beginning with the *Commander Keen* series (1990–91). Based on the success of this series, the group formed id Software in February 1991.

From the beginning, id focused on the development of superior graphics. Carmack had already demonstrated, by writing a smoothly scrolling version of *Nintendo's Super Mario Brothers 3*, that PCs could rival video consoles. Now he turned his attention to three-dimensional gaming graphics, writing a "graphics engine" for id's *Wolfenstein 3-D*, an action game published by Apogee, that depicted the environment as the player's character would see it. This set the stage for *DOOM* as the next step of this game genre, the first-person shooter. *DOOM* added numerous technical and design improvements: a superior graphics engine, fast peer-to-peer networking for multiplayer gaming, a modular design that let authors outside id create new levels, and a new mode of competitive play devised by Romero called "death match."

DOOM was a phenomenal success, immediately establishing competitive multiplayer gaming as a leading genre of PC games. At the same time, the subject matter of *DOOM* (slaughtering demons in outer space), its moody graphics and audio, and its vocabulary (such as "shooters" and "death match") focused public attention on the level of violence depicted in computer games. In 1997 the U.S. Marine Corps converted *DOOM*'s monsters into opposition forces and used the resulting game, *Marine Doom*, to train troops in tactics and communications.

Marine Doom

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(H.E.L.)

Electronics

Electronics encompasses an exceptionally broad range of technology. The term originally was applied to the study of electron behaviour and movement, particularly as observed in the first electron tubes. It came to be used in its broader sense with advances in knowledge about the fundamental nature of electrons and about the way in which the motion of these particles could be utilized. Today many scientific and technical disciplines deal with different aspects of electronics. Research in these fields has led to the development of such key devices as transistors, integrated circuits, lasers, and optical fibres. These in turn have made it possible to manufacture a wide array of electronic consumer, industrial, and military products. Indeed, it can be said that the world is in the midst of an electronic revolution at least as significant as the industrial revolution of the 19th century.

This article reviews the historical development of electronics, highlighting major discoveries and advances. It also describes some key electronic functions and the manner in which various devices carry out these functions.

For coverage of other related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 125, 127, 712, 721, 735, and 738, and the *Index*.

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The history of electronics

THE VACUUM TUBE ERA

Theoretical and experimental studies of electricity during the 18th and 19th centuries led to the development of the first electrical machines and the beginning of the widespread use of electricity. The history of electronics began to evolve separately from that of electricity late in the 19th century with the identification of the electron by the English physicist Sir Joseph John Thomson and the measurement of its electric charge by the American physicist Robert A. Millikan in 1909.

At the time of Thomson's work, the American inventor Thomas A. Edison had observed a bluish glow in some of his early lightbulbs under certain conditions and found that a current would flow from one electrode in the lamp to another if the second one (anode) were made positively charged with respect to the first (cathode). Work by Thomson and his students and by the English engineer John Ambrose Fleming revealed that this so-called Edison effect was the result of the emission of electrons from the cathode, the hot filament in the lamp. The motion of the electrons to the anode, a metal plate, constituted an electric current that would not exist if the anode were negatively charged.

Edison effect

This discovery provided impetus for the development of electron tubes, including an improved X-ray tube by the American engineer William D. Coolidge and Fleming's thermionic valve (a two-electrode vacuum tube) for use in radio receivers. The detection of a radio signal, which is a very high-frequency alternating current (AC), requires that the signal be rectified; *i.e.*, the alternating current must be converted into a direct current (DC) by a device that conducts only when the signal has one polarity but not when it has the other—precisely what Fleming's valve (patented in 1904) did. Previously, radio signals were detected by various empirically developed devices such as the "cat whisker" detector, which was composed of a fine wire (the whisker) in delicate contact with the surface of a natural crystal of lead sulfide (galena) or some other semiconductor material. These devices were undependable, lacked sufficient sensitivity, and required constant adjustment of the whisker-to-crystal contact to produce the desired result. Yet these were the forerunners of today's solid-state devices. The fact that crystal rectifiers worked at all encouraged scientists to continue studying them and gradually to obtain the fundamental understanding of the electrical properties of semiconducting materials necessary to permit the invention of the transistor.

In 1906 Lee De Forest, an American engineer, developed a type of vacuum tube that was capable of amplifying radio signals. De Forest added a grid of fine wire between the cathode and anode of the two-electrode thermionic valve constructed by Fleming. The new device, which De Forest dubbed the Audion, was thus a three-electrode vacuum tube. In operation, the anode in such a vacuum tube is given a positive potential (positively biased) with respect to the cathode, while the grid is negatively biased. A large negative bias on the grid prevents any electrons emitted from the cathode from reaching the anode; however, because the grid is largely open space, a less negative bias permits some electrons to pass through it and reach the anode. Small variations in the grid potential can thus control large amounts of anode current.

Audion

The vacuum tube permitted the development of radio broadcasting, long-distance telephony, television, and the first electronic digital computers. These early electronic computers were, in fact, the largest vacuum-tube systems ever built. Perhaps the best-known representative is the ENIAC (Electronic Numerical Integrator and Computer), completed in 1946.

The special requirements of the many different applications of vacuum tubes led to numerous improvements, enabling them to handle large amounts of power, operate at very high frequencies, have greater than average reliability,

or be made very compact (the size of a thimble). The cathode-ray tube, originally developed for displaying electrical waveforms on a screen for engineering measurements, evolved into the television picture tube. Such tubes operate by forming the electrons emitted from the cathode into a thin beam that impinges on a fluorescent screen at the end of the tube. The screen emits light that can be viewed from outside the tube. Deflecting the electron beam causes patterns of light to be produced on the screen, creating the desired optical images.

Other specialized types of vacuum tubes, developed or refined during World War II for military purposes, are still used today in microwave ovens and as extremely high-frequency transmitters aboard space satellites. Notwithstanding the remarkable success of solid-state devices in most electronic applications, there are certain specialized functions that only vacuum tubes can perform. These usually involve operation at extremes of power or frequency. Vacuum tubes continue to be used as display devices for television sets and computer monitors because other means of providing the function are more expensive, though even this situation is changing.

Vacuum tubes are fragile and ultimately wear out in service. Failure occurs in normal usage either from the effects of repeated heating and cooling as equipment is switched on and off (thermal fatigue), which ultimately causes a physical fracture in some part of the interior structure of the tube, or from degradation of the properties of the cathode by residual gases in the tube. Vacuum tubes also take time (from a few seconds to several minutes) to "warm up" to operating temperature—an inconvenience at best and in some cases a serious limitation to their use. These shortcomings motivated scientists at Bell Laboratories to seek an alternative to the vacuum tube and led to the development of the transistor.

Bell Laboratories

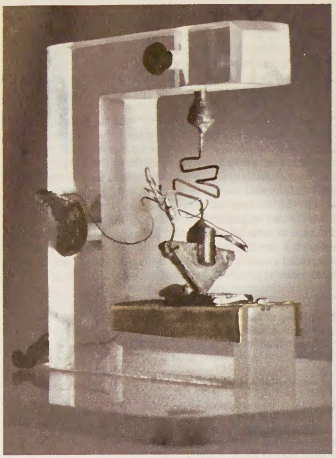

Figure 1: The first transistor, invented by American physicists John Bardeen, Walter Brattain, and William Shockley.
Lucent Technologies Inc./Bell Labs

THE SEMICONDUCTOR REVOLUTION

Invention of the transistor. The invention of the transistor in 1947–48 by John Bardeen, Walter H. Brattain, and William B. Shockley of the Bell research staff provided the first of a series of new devices with remarkable potential for expanding the utility of electronic equipment. Transistors, along with such subsequent developments as integrated circuits, are made of crystalline solid materials called semiconductors, which have electrical properties that can be varied over an extremely wide range by the addition of minuscule quantities of other elements. The electric current in semiconductors is carried by electrons, which have a negative charge, and also by "holes," analogous entities that carry a positive charge. The availability of two kinds of charge carriers in semiconductors is a valuable property exploited in many electronic devices made of such materials.

Early transistors were produced using germanium as the semiconductor material, because methods of purifying it to the required degree had been developed during and shortly after World War II. Because the electrical properties of semiconductors are extremely sensitive to the slightest trace of certain other elements, only about one part per billion of such elements can be tolerated in material to be used for making semiconductor devices.

During the late 1950s, research on the purification of silicon succeeded in producing material suitable for semiconductor devices, and new devices made of silicon were manufactured from about 1960. Silicon quickly became the preferred raw material, because it is much more abundant than germanium and thus less expensive. In addition, silicon retains its semiconducting properties at higher temperatures than does germanium. Silicon diodes can be operated at temperatures up to 200 °C (400 °F), whereas germanium diodes cannot be operated above 85 °C (185 °F). There was one other important property of silicon, not appreciated at the time but crucial to the development of low-cost transistors and integrated circuits: silicon, unlike germanium, forms a tenaciously adhering oxide film with excellent electrical insulating properties when it is heated to high temperatures in the presence of oxygen. This film is utilized as a mask to permit the desired impurities that modify the electrical properties of silicon to be introduced into it during manufacture of semiconductor devices. The mask pattern, formed by a photolithographic process, permits the creation of tiny transistors and other electronic components in the silicon.

Integrated circuits. By 1960 vacuum tubes were rapidly being supplanted by transistors, because the latter had become less expensive, did not burn out, and were much smaller and more reliable. Computers employed hundreds of thousands of transistors each. This fact, together with the need for compact, lightweight electronic missile-guidance systems, led to the invention of the integrated circuit (IC) independently by Jack Kilby of Texas Instruments Incorporated in 1958 and by Jean Hoerni and Robert Noyce of Fairchild Semiconductor Corporation in 1959. Kilby is usually credited with having developed the concept of integrating device and circuit elements onto a single silicon chip, while Noyce is given credit for having conceived the method for integrating the separate elements.

Early ICs contained about 10 individual components on a silicon chip 3 millimetres (0.12 inch) square. By 1970 the number was up to 1,000 on a chip of the same size at no increase in cost. Late in the following year the first microprocessor was introduced. The device contained all the arithmetic, logic, and control circuitry required to perform the functions of a computer's central processing unit (CPU). This type of large-scale IC was developed by a team at Intel Corporation, the same company that also introduced the memory IC in 1971. The stage was now set for the computerization of small electronic equipment.

Intel Corporation

Until the microprocessor appeared on the scene, computers were essentially discrete pieces of equipment used primarily for data processing and scientific calculations. They ranged in size from minicomputers, comparable in dimensions to a small filing cabinet, to mainframe systems that could fill a large room. The microprocessor enabled computer engineers to develop microcomputers—systems about the size of a lunch box or smaller but with enough computing power to perform many kinds of business, industrial, and scientific tasks. Such systems made it possible to control a host of small instruments or devices (*e.g.*, numerically controlled lathes and one-armed robotic devices for spot welding) by using standard components programmed to do a specific job.

The large demand for microprocessors generated by these initial applications led to high-volume production and a dramatic reduction in cost. This in turn promoted the use of the devices in many other applications—for example, in household appliances and automobiles, for which electronic controls had previously been too expensive to consider. Continued advances in IC technology gave rise to very large-scale integration (VLSI), which substantially increased the circuit density of microprocessors. These technological advances, coupled with further cost reductions stemming from improved manufacturing methods, made feasible the mass production of personal computers for use in offices, schools, and homes.

By the mid-1980s inexpensive microprocessors had stimulated computerization of an enormous variety of consumer products. Common examples included programmable microwave ovens and thermostats, clothes washers and dryers, self-tuning television sets and self-focusing cameras, videocassette recorders and video games, telephones and answering machines, musical instruments, watches, and security systems. Microelectronics also came to the fore in business, industry, government, and other sectors. Microprocessor-based equipment proliferated, ranging from automatic teller machines (ATMs) and point-of-sale terminals in retail stores to automated factory assembly systems and office workstations.

By mid-1986 memory ICs with a capacity of 262,144 bits (binary digits) were available. In fact, Gordon E. Moore, one of the founders of Intel, observed as early as 1965 that the complexity of ICs was approximately doubling every 18–24 months, which was still the case in 2000. This empirical "Moore's law" is widely used in forecasting the technological requirements for manufacturing future ICs.

Moore's law

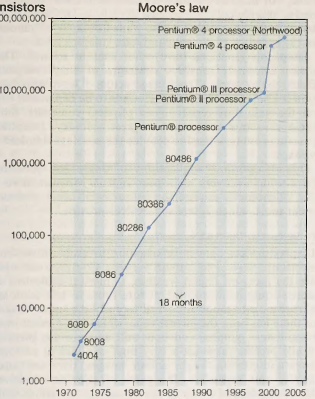

Figure 2: Moore's law, showing the number of transistors per processor.

Compound semiconductor materials. Many semiconductor materials other than silicon and germanium exist, and they have different useful properties. Silicon carbide is a compound semiconductor, the only one composed of two elements from column IV of the periodic table. It is particularly suited for making devices for specialized high-temperature applications. Other compounds formed by combining elements from column III of the periodic table—such as aluminum, gallium, and indium—with elements from column V—such as phosphorus, arsenic, and antimony—are of particular interest. These III-V compounds are used to make semiconductor devices that emit light efficiently or that operate at exceptionally high frequencies.

A remarkable characteristic of these compounds is that they can, in effect, be mixed together. One can produce gallium arsenide or substitute aluminum for some of the gallium or also substitute phosphorus for some of the arsenic. When this is done, the electrical and optical properties of the material are subtly changed in a continuous fashion in proportion to the amount substituted.

Except for silicon carbide, these compounds have the same crystal structure. This makes possible the gradation of composition, and thus the properties, of the semiconductor material within one continuous crystalline body. Modern material-processing techniques allow these compositional changes to be controlled on an atomic scale.

These characteristics are exploited in making semiconductor lasers that produce light of any given wavelength within a considerable range. Such lasers are used, for example, in compact disc players and as light sources for optical fibre communication.

DIGITAL ELECTRONICS

Computers understand only two numbers, 0 and 1, and do all their arithmetic operations in this binary mode. Many electrical and electronic devices have two states: they are either off or on. A light switch is a familiar example, as are vacuum tubes and transistors. Because computers have been a major application for integrated circuits from their beginning, digital integrated circuits have become commonplace. It has thus become easy to design electronic systems that use digital language to control their functions and to communicate with other systems.

A major advantage in using digital methods is that the accuracy of a stream of digital signals can be verified, and, if necessary, errors can be corrected. In contrast, signals that vary in proportion to, say, the sound of an orchestra can be corrupted by "noise," which once present cannot be removed. An example is the sound from a phonograph record, which always contains some extraneous sound from the surface of the recording groove even when the record is new. The noise becomes more pronounced with wear. Contrast this with the sound from a digital compact disc recording. No sound is heard that was not present in the recording studio. The disc and the player contain error-correcting features that remove any incorrect pulses (perhaps arising from dust on the disc) from the information as it is read from the disc.

As electronic systems become more complex, it is essential that errors produced by noise be removed; otherwise, the systems may malfunction. Many electronic systems are required to operate in electrically noisy environments, such as in an automobile. The only practical way to assure immunity from noise is to make such a system operate digitally. In principle it is possible to correct for any arbitrary number of errors, but in practice this may not be possible. The amount of extra information that must be handled to correct for large rates of error reduces the capacity of the system to handle the desired information, and so trade-offs are necessary.

A consequence of the veritable explosion in the number and kinds of electronic systems has been a sharp growth in the electrical noise level of the environment. Any electrical system generates some noise, and all electronic systems are to some degree susceptible to disturbance from noise. The noise may be conducted along wires connected to the system, or it may be radiated through the air. Care is necessary in the design of systems to limit the amount of noise that is generated and to shield the system properly to protect it from external noise sources.

Environmental noise

OPTOELECTRONICS

A new direction in electronics employs photons (packets of light) instead of electrons. By common consent, these new approaches are included in electronics, because the functions that are performed are, at least for the present, the same as those performed by electronic systems and because these functions usually are embedded in a largely electronic environment. This new direction is called optical electronics or optoelectronics.

In 1966 it was proposed on theoretical grounds that glass fibres could be made with such high purity that light could travel through them for great distances. Such fibres were

produced during the early 1970s. They contain a central core in which the light travels. The outer cladding is made of glass of a different chemical formulation and has a lower optical index of refraction. This difference in refractive index indicates that light travels faster in the cladding than it does in the core. Thus, if the light beam begins to move from the core into the cladding, its path is bent so as to move it back into the core. The light is constrained within the core even if the fibre is bent into a circle.

The core of early optical fibres was of such a diameter (several microns [millionths of a metre], or about one-tenth the diameter of a human hair) that the various rays of light in the core could travel in slightly different paths, the shortest directly down the axis and other longer paths wandering back and forth across the core. This limited the maximum distance that a pulse of light could travel without becoming unduly spread by the time it arrived at the receiving end of the fibre, with the central ray arriving first and others later. In a digital communications system, successive pulses can overlap one another and be indistinguishable at the receiving end. Such fibres are called multimode fibres, in reference to the various paths (or modes) that the light can follow.

During the late 1970s, fibres were made with smaller core diameters in which the light was constrained to follow only one path. This occurs if the core has a diameter a little larger than the wavelength of the light traveling in it—*i.e.*, about 10 to 15 microns (0.0004 to 0.0006 inch). These single-mode fibres avoid the difficulty described above. By 1993 optical fibres capable of carrying light signals more than 215 kilometres (135 miles) became available. Such distance records have become obsolete with the use of specialized fibres that incorporate integral amplifying features. Fibres employing these optical amplifiers carry light signals over transoceanic distances without the conventional pulse regeneration measures that were needed in the past.

Optical fibres have several advantages over copper wires or coaxial cables. They can carry information at a much higher rate, they occupy less space (an important feature in large cities and in buildings), and they are quite insensitive to electrical noise. Moreover, it is virtually impossible to make unauthorized connections to them. Costs, initially high, have dropped to the point where most new installations of telephone circuits between switching centres and over longer distances consist of optical fibres.

Optical switches

Given the fact that communication signals arrive at a central switching office in optical form, it has been attractive to consider switching them from one route to another by optical means rather than electrically, as is done today. The distances between central offices in most cases are substantially shorter than the distance light can travel within a fibre. Optical switching would make unnecessary the detection and regeneration of the light signals, steps that are currently required. Such optical central-office switches are ready for installation today and will further advance the dramatic changes wrought by the use of light waves rather than electrons.

Another direction in optoelectronics builds in part on the foregoing developments but to a quite different end. A key problem in developing faster computers and faster integrated circuits to use in them is related to the time required for electrical signals to travel over wire interconnections. This is a difficulty both for the integrated circuits themselves and for the connections between them. Under the best circumstances, electrical signals can travel in a wire at about 90 percent of the speed of light. A more usual rate is 50 percent. Light travels about 30 centimetres (12 inches) in a billionth of a second. Modern computers operate at speeds of more than one billion operations per second. Thus, if two signals that start simultaneously from different sites are to arrive at their destination simultaneously, the paths they travel must not differ in length by more than a few centimetres.

Two approaches can be envisioned. In one, all the integrated circuits are placed as close together as possible to minimize the distances that signals must travel. This creates a cooling problem, because the integrated circuits generate heat. In the other possible approach, all the paths for signals are made equal to the longest path. This requires the use of much more wire, because most paths are longer than they would otherwise be. All this wire takes space, which means that the integrated circuits have to be placed farther apart than is preferable.

Ultimately, as computers operate even faster, neither approach will work, and a radically new technique must be used. Optical communication between integrated circuits is one possible answer. Light beams do not take up space or interfere with cooling air. If the communication is optical, then the computation might be done optically as well. Optical computation will require a radically different form of integrated circuit, which can in principle be made of gallium arsenide and related III-V compounds. These matters are currently under serious study in research laboratories.

SUPERCONDUCTING ELECTRONICS

Numerous metals completely lose their resistance to the flow of electric current at temperatures approaching absolute zero (0 K, −273 °C, or −460 °F) and become superconducting. Other equally dramatic changes in electrical properties occur as well. One of these is the Josephson effect, named for the British physicist Brian D. Josephson, who predicted and then discovered the phenomenon in 1962. The Josephson effect governs the passage of current from one superconducting metal to another through a very thin insulating film between them (the Josephson junction) and the effects of small magnetic fields on this current.

Josephson junction

Josephson junction devices change from one electrical state to another in extraordinarily short times, offering the possibility of producing superconducting microcircuits that operate faster than any other kind known. Serious efforts have been made to construct a computer on this basis, but most of the projects have been either discontinued or sharply cut back because of technical difficulties. Interest in the approach has also waned because of increases in the speed of III-V semiconductor microcircuits.

Josephson junctions have other uses in science. They make extremely sensitive detectors of small magnetic fields, for example. The voltage across a Josephson junction is known on theoretical grounds to be dependent only on the values of certain basic physical constants. Since these constants are known to great accuracy, Josephson junctions are now used to provide the absolute standard of voltage.

Other important applications of Josephson junctions have to do with very high-speed signals. Measurements of fast phenomena require the use of even faster measurement tools, which Josephson devices provide.

FLAT-PANEL DISPLAYS

Display devices convey information in visible form from electronic devices to human viewers. Common examples are the faces on digital watches, numerical indicators on stereo equipment, and the picture tubes in television sets and computer monitors. Until recently the most versatile of these has been the picture tube, which can present numbers, letters, graphs, and both still and moving pictures. While picture tubes set a very high standard of performance and provide bright colour images, they are bulky, heavy, and expensive. Designers of television receivers have long desired a display device having the virtues of the picture tube but fewer of the disadvantages, so that a "picture on the wall" television set can be produced.

New developments in flat-panel displays have made this possible. Such displays are advanced versions of the liquid crystal display familiar in digital watch faces. They are essentially two parallel sheets of thin glass having the facing sides coated with a transparent yet electrically conducting film such as indium tin oxide. The film layer nearer the viewer is patterned, while the other layer is not. The space between the films is filled with a fluid with unusual electrical and optical properties, so that, if an electrical field is established between the two thin films, the molecules of the fluid line up in such a way that the light-reflecting or light-transmitting properties of the assembly are radically changed. The electro-optical fluid is an electrical insulator, so very little electric current flows. Thus, almost no power is consumed, making the display well suited for use in bat-

tery-powered applications. All flat-panel displays have these characteristics in common, but the many different varieties exploit the electro-optical effects in numerous ways.

Displays that produce images are patterned with myriads of tiny picture elements that can be electrically activated independently to produce patterns of light and dark or arbitrary forms. Superposed colour filters having arrays of elements corresponding to those in the display permit the formation of colour images of a quality rivaling that of colour cathode-ray tube displays. Such displays are used as viewing devices for television sets, computers, and video and digital cameras.

Colour displays capable of serving as television screens or computer displays are available in sizes of more than 35 centimetres (15 inches) on the diagonal, at costs nearly competitive with picture tubes. There is strong demand for them in laptop computers, where the thinness of a flat-panel display is essential. Such displays have more than three million separate elements in the picture array, each of which must have separate means for its control. The control electronics is integrated into the display, for otherwise the number of individual wires needed to connect with the rest of the circuitry would be prohibitive.

A great amount of effort is being expended to increase the size and decrease the cost of flat-panel displays, because the potential market for them is clearly substantial. Much of the reduction in cost is obtained through experience in manufacturing, where low yields attributable to defects in the patterns have been a major problem.

The science of electronics

VALENCE ELECTRONS

Since electronics is concerned with the control of the motion of electrons, one must keep in mind that electrons, being negatively charged, are attracted to positive charges and repelled by other negative charges. Thus, electrons in a vacuum tend to space themselves apart from one another and form a cloud, subject to the influences of other charges that may be present. An electric current is created by the motion of electrons, whether in a vacuum, in a wire, or in any other electrically conducting medium. In each of these cases, electrons move as a result of their attraction to positive charges or repulsion from negative ones.

An atom consists of a nucleus of protons and neutrons around which electrons, equal in number to the protons in the nucleus, travel in orbits much like those of the planets around the Sun. Because of this equality in the number of positively and negatively charged constituent particles, the atom as a whole is electrically uncharged. When atoms are combined into certain solids called covalent solids (notably the elements of column IV of the periodic table), the valence electrons (outer electrons) are shared between neighbouring atoms, and the atoms thereby become bound together. This occurs not only in elemental solids, wherein all the atoms are of the same kind, but also in chemical compounds (*e.g.*, the III-V compounds).

Covalent solids

Different materials vary greatly in their ability to conduct electricity, depending directly on the ease or difficulty of setting electrons free from their atoms. In insulating materials all the outermost electrons of the atoms are tightly bound in the chemical bonds between atoms and are not free to move. In metals there are more valence electrons than are required for bonding, and these excess electrons are freely available for electrical conduction.

Most insulators and metals are crystalline materials but are composed of a great many very small crystals. (In all crystals the atoms are positioned in a regularly spaced three-dimensional array.) Semiconducting solids for electronic applications, however, are prepared as single large crystals. The fact that the atoms in a semiconductor are arranged in a periodic, three-dimensional array of large size (large, that is, in comparison with an atom) makes the atoms appear nearly invisible to electrons moving within a crystal. The reasons for this behaviour are too complex to explain here, but this property allows electrons to be quite mobile in semiconductors.

Conduction in semiconductors. In semiconductors such as silicon (which is used as the example here), each constituent atom has four outer electrons, each of which pairs with an electron from one of four neighbouring atoms to form the interatomic bonds. Completely pure silicon thus has essentially no electrons available at room temperature for electronic conduction, making it a very poor conductor. However, if an atom from column V of the periodic table, such as phosphorus, is substituted for an atom of silicon, four of its five outer electrons will be used for bonding, while the fifth will be free to move within the crystal (see Figure 3). If the replacement atom comes from column III of the periodic table—say, boron—it will have only three outer electrons, one too few to complete the four interatomic bonds. The fact that the crystal would be electrically neutral were this bond complete means that, if an electron is missing, the vacancy will have a positive charge. A neighbouring electron can move into the vacancy, leaving another vacancy in the electron's former place. This vacancy, with its positive charge, is thus mobile and is called a "hole." Holes move about as readily as electrons do, but in directions opposite to the motion of electrons.

Semiconductors whose principal charge carriers are electrons are called *n*-type (*n* standing for negative). If the charge carriers are mainly holes, the material is *p*-type (*p* for positive). The process of substituting elements for the silicon (in this example) is called doping, while the elements are referred to as dopants. The amount of dopant that is required in practical devices is very small, ranging from about 100 dopant atoms per million silicon atoms downward to 1 per billion.

Doping

Fabrication of semiconductors. Dopants may be added to the silicon either during the crystal growth process or later. The basic technique for creating large single crystals was discovered by the Polish chemist Jan Czochralski in 1916 and is now known as the Czochralski method. To create a single crystal of silicon by using the Czochralski method, electronic-grade silicon (refined to less than one part impurity in 100 billion) is heated to about 1,500 °C (2,700 °F) in a fused quartz crucible. Either an electron-donating element such as phosphorus or arsenic (for *p*-type semiconductors) or an electron-accepting element such as boron (for *n*-type semiconductors) is mixed in at a concentration of a few parts per billion. A small "seed" crystal, with a diameter of about 0.5 centimetre (0.2 inch) and a length of about 10 centimetres (4 inches), is attached to the end of a rod and lowered until it just penetrates the molten surface of the silicon. The rod and the crucible are then rotated in opposite directions while the rod is slowly

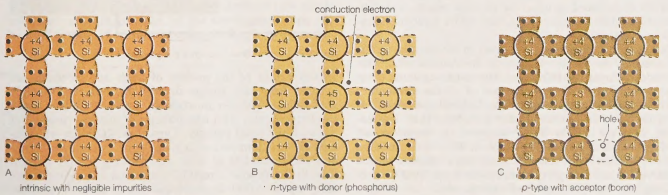

Figure 3: Three bond pictures of a semiconductor.

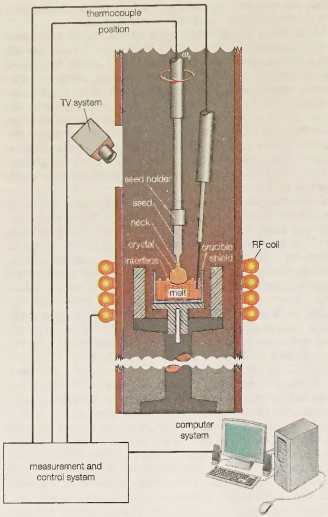

Figure 4: Czochralski method of crystal pulling.

withdrawn a few millimetres per second. (See Figure 4.) Properly synchronized, these procedures result in the slow growth of a single crystal. After many days the single crystal can be more than 1 metre (3.3 feet) in length and 300 millimetres (11.8 inches) in diameter. After growth the silicon crystal is ground to a smooth cylindrical shape and sliced into wafers approximately 0.6 millimetre (0.02 inch) thick using diamond tools. The surfaces of the wafers are polished flat by a series of successively finer abrasives until one side has a perfect mirror finish.

The process of fabricating semiconductor devices is a complex series of more than 600 sequential steps, all of which must be done with utmost precision in an environment cleaner than a hospital operating room. The objective is to add the correct dopants to the silicon in the proper amounts in the right places and to connect the transistors thus produced with thin films of metals separated by other thin films of insulating materials. The scale of lateral dimensions in integrated circuits ranged down to 0.13 micron (0.000005 inch) in 2001 and continues to decrease year by year. A high-power semiconductor device for industrial use, on the other hand, may be so large as to require a slice of silicon measuring well over 125 millimetres (5 inches) in diameter.

State of the art. The importance of having a thorough, detailed understanding of all the physical effects related to materials, fabrication processes, and device structures cannot be overstated.

The motion of electrons and holes in semiconductors is governed by the theory of quantum mechanics, which was developed during the 1920s and '30s as a much more comprehensive theory of the behaviour of all the elementary particles that make up matter. The electrical and optical effects observed in semiconductor materials, their interactions, and the effects of temperature on them are all understood in nearly complete detail. This understanding not only makes it possible to explain quantitatively what is observed in laboratory experiments but is essential for predicting how new processes and devices work.

The research necessary to develop such a detailed theoretical and experimental body of knowledge was initiated during the late 1940s and has continued in industrial, university, and government laboratories ever since. It is now possible to design new semiconductor devices to perform in a completely predictable fashion by calculating their performance from theory and from their physical configuration, with the aid of computers.

The fabrication processes used to make real devices are not as well understood, although much has been learned. Theoretical designs incorporate the assumptions that the materials are entirely pure, that dopants exist only in the proper amounts and distributions, and that the dimensions of structures have the intended values. These assumptions are true in practice only to a limited degree. Major efforts in universities and company laboratories are focused on better understanding these issues and on developing improved computer-based modeling and process-design methods. Large sums of money are spent to provide equipment and manufacturing environments that adequately control each process step and protect the material being processed from contamination.

BASIC ELECTRONIC FUNCTIONS

Rectification. Rectification, or conversion of alternating current (AC) to direct current (DC), is mentioned above in the section *The vacuum tube era*. A diode, or two-terminal device, is required for this process. Semiconductor diodes consist of a crystal, part of which is *n*-type and part *p*-type. The boundary between the two parts is called a *p-n* junction (see Figure 5). As noted above, there is a population of holes on the *p*-type side of the junction and a population of electrons on the *n*-type side. If a negative voltage is applied to the *p*-type side, implying a positive voltage applied to the *n*-type side, the holes in the *p*-type region will be attracted away from the *p-n* junction, as will the electrons on the *n*-type side. A region on either side of the *p-n* junction will be depleted of charge carriers, thus becoming effectively an insulator. In this condition, called reverse bias, only a very small leakage current flows.

Semiconductor diodes

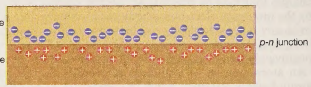

Figure 5: A *p-n* junction.

If these voltages are reversed, however, creating a condition called forward bias, the positive voltage on the *p*-type side will repel holes across the *p-n* junction; the negative voltage will repel the electrons on the *n*-type side. Both holes and electrons will cross the *p-n* junction in opposing directions, creating an electric current (see Figure 6).

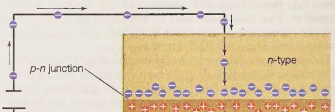

Figure 6: Electron flow through a *p-n* junction.

Many details of the motion of holes and electrons are omitted from this simple description, but the principle seems clear. The *p-n* junction in a semiconductor diode conducts current with one polarity of applied voltage but not with the other polarity. Typical small diodes will conduct about 0.1 ampere with roughly a 1.5-volt forward bias and withstand 100 or more volts with negligible current flow in the reverse direction. Large industrial diodes can carry up to 5,000 amperes and block several thousand volts.

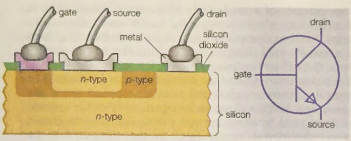

Figure 7: Cross section of an *n-p-n* transistor.

Amplification. *Using n-p-n transistors.* A transistor is constructed with two *p-n* junctions parallel and very close to one another. A typical configuration is the *n-p-n* transistor (see Figure 7), which has different levels of doping in the two *n*-type regions and other features that improve its efficiency; in the design shown in the diagram, the *n-p-n* regions correspond to the source (or emitter), gate (or base), and drain (or collector) of the circuit. In normal operation, such as in an amplifier circuit (see Figure 8), there are provisions (batteries in this case) for applying a small forward bias to the base-emitter junction and a larger reverse bias to the base-collector junction. Resistors are arranged in series with each battery to establish steady-state operating conditions, and an AC signal source is contained in the base lead. When the AC signal source is switched off, the battery in the emitter-base circuit causes a small current to flow through the series resistor and the forward-biased emitter-base junction. This results in excess electrons being present in the *p*-type base region of the transistor. Many more of these electrons are attracted to the collector region by the strong reverse bias on the collector than are attracted to the base connection. In an average *n-p-n* transistor, more than 100 electrons pass from the emitter to the collector for each 1 that passes from the emitter to the base.

Collector current

When the AC signal source is switched on, the base current is increased and decreased alternately. The collector current varies in the same way but to a hundredfold larger extent; in effect, the signal has been amplified. The varying collector current through the collector series resistor causes a varying voltage drop, which may be used as the signal source for a subsequent amplifying circuit. This example employs an *n-p-n* transistor. With a *p-n-p* transistor, the action is similar except that holes are the primary charge carriers, and the voltages of the batteries and thus the direction of current are reversed.

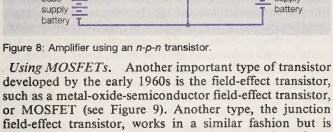

Figure 8: Amplifier using an *n-p-n* transistor.

Using MOSFETs. Another important type of transistor developed by the early 1960s is the field-effect transistor, such as a metal-oxide-semiconductor field-effect transistor, or MOSFET (see Figure 9). Another type, the junction field-effect transistor, works in a similar fashion but is much less frequently used. The MOSFET consists of two regions: (1) the source (here shown connected to the silicon substrate) and (2) the drain of one conductivity type embedded in a body of the opposite conductivity type. The space between the source and the drain is covered by a thin layer of silicon dioxide formed by heating the silicon in an oxidizing atmosphere. A third part of the device, the gate, is a thin metal layer deposited on the silicon dioxide.

There are several types of MOSFETs, including an *n*-channel type, so designated because, when it is in operation, the application of a positive voltage to the gate with respect to the *p*-type region causes a thin conducting region containing mostly electrons to form in the *p*-type region just beneath the gate. The gate voltage repels holes and attracts electrons from the *p*-type region, in which there are some electrons even though the principal charge carriers are holes. The thin layer of electron-rich material, the channel, connects the source and drain electrically and permits current to flow between them when the drain is biased positively with respect to the source. The amount of current is controlled by the gate voltage. Without gate voltage, no current flows, because the *p-n* junction around the drain region is reverse-biased and because no channel exists. MOSFETs are widely used in integrated circuits.

Coupling amplifiers. The existence of more than one type of transistor gives the circuit designer additional freedom not available for vacuum tube circuits and allows many clever circuits to be constructed. This becomes apparent in the direct coupling of successive amplifier stages. There are many ways to couple a signal from one circuit to another. Each has its advantages and disadvantages. Consideration must be given to the voltage levels in the circuits. In cases where the voltage level at the collector of the first amplifier is different from that at the base of the second, a direct connection could not be used. A transformer could be employed for coupling, with its primary in the collector circuit of the first amplifier and its secondary in the base circuit of the second one. However, transformers often do not exhibit uniform behaviour over a wide range of frequencies, which can be a problem. Transformers also are expensive and bulky. Similarly, a capacitor could be inserted between the collector of the first amplifier and the base of the second. This works well for many applications, providing uniform coupling inexpensively over a wide frequency range. At low frequencies, capacitive coupling becomes ineffective, however.

The use of a second, *p-n-p* amplifier allows direct connection between the amplifiers (see Figure 10). If properly designed, this arrangement provides useful amplifying properties from DC to quite high frequencies. Care is required to avoid any changes in the DC operating conditions of the first amplifier; such changes will cause an amplified change in the DC conditions of the second one. Changes in temperature, in particular, can cause changes in resistor values and changes in the amplification properties of transistors. These factors must be carefully taken into account. Judicious use of feedback from later parts of a circuit to earlier ones can be utilized to stabilize such circuits or to perform various other useful functions (see below *Oscillation*). In negative feedback, the feedback signal is of a sense opposite to the signal present at the point

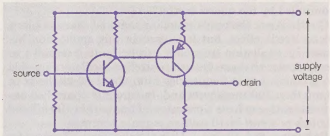

Figure 10: Direct coupled *n-p-n-p-n-p* amplifier.

in the circuit where the feedback signal is applied. While this has the effect of reducing the overall gain of the circuit, it also corrects numerous small distortions that may have occurred in the signal. For example, if the amplifier does not amplify large signals as much as small ones, the feedback from larger signals will be less, as will the reduction in gain, and the larger signals will be increased in the output of the circuit. Thus the distortion is reduced.

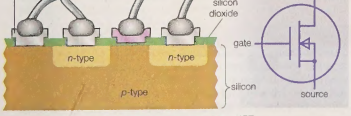

Figure 9: Cross section of an *n*-channel MOSFET.

Oscillation. Positive feedback signals reinforce the original one, and an amplifier can be made to oscillate, or generate an AC signal. Such signals are needed for many purposes and are created in numerous kinds of oscillator circuits. In a tunable oscillator, such as that required for a radio receiver, the parallel combination of an inductor and a capacitor is a tuned circuit: at one frequency, and only one, the inductive effects and the capacitive effects balance. At this frequency the voltage developed across the tuned circuit is a maximum. Positive feedback is provided by the inductor in the collector circuit, which is magnetically coupled to the inductor of the tuned circuit. The connections to these inductors are arranged so that, when the collector current increases, the voltage at the base also increases, thus causing the collector current to rise further. The action of the tuned circuit reverses this sequence after a time and causes the base voltage to start to fall. This reduces the collector current; the positive feedback then further reduces the base voltage, and so on.

Tunable oscillator

The circuit is in fact an amplifier whose output provides the input signal. The tuned circuit affects the feedback process in such a way that the circuit responds to an input signal at only one frequency—namely, the frequency to which the inductor and capacitor are tuned. The variable capacitor provides a way to adjust the frequency of oscillation. The output signal is obtained from the emitter resistor, through which the current rises and falls in synchrony with the collector current.

Oscillators that produce a single, accurate frequency are often needed. Such an oscillator is used in electronic watches. Other circuits in the watch count the output signals from the oscillator to determine the passage of time. These oscillators use a quartz crystal instead of a tuned circuit to establish the operating frequency (see Figure 11).

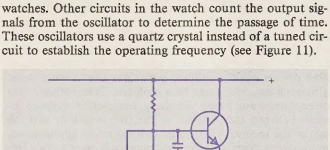

Figure 11: Quartz crystal oscillator.

Quartz has the useful properties of changing its dimensions slightly if an electric field is applied to it and, conversely, of producing a small electrical voltage when pressure is applied (the piezoelectric effect). In a quartz crystal oscillator a small plate of quartz is provided with metal electrodes on its faces. Just as a bell rings when struck, the quartz plate also "rings," but at a very high frequency, and produces an AC voltage between the electrodes. When such a crystal is used in an oscillator, positive feedback provides energy to the quartz crystal to keep it ringing, and the oscillator output frequency is precisely controlled by the quartz crystal.

Piezoelectric effect

Quartz is not the only crystalline material that exhibits a piezoelectric effect, but it is used in this application because its oscillation frequency can be quite insensitive to temperature changes. Quartz-controlled oscillators are able to produce output frequencies from about 10 kilohertz to more than 200 megahertz and, in carefully controlled environments, can have a precision of one part in 100 billion, though one part in 10 million is more common.

Switching and timing. *Using transistors.* Transistors in amplifier circuits are used as linear devices; i.e., the input signal and the larger output signal are nearly exact replicas of each other. Transistors and other semiconductor devices may also be used as switches. In such applications the base or gate of a transistor, depending on the type of transistor in use, is employed as a control element to switch on or off the current between the emitter and collector or the source and drain. The purpose may be as simple as lighting an indicator lamp, or it may be of a much more complex nature.

An example of a moderately sophisticated application is in a backup, or "uninterruptible," power source for a computer. Such equipment consists of a storage battery (which is normally kept charged by rectifying the power coming from the AC power line), a circuit for converting the battery power into AC, and the necessary control circuits. The control circuits monitor the voltage supplied from the power line. If this voltage varies significantly either upward or downward from its normal values, the control circuit causes the power supply lines to the computer to be switched from the incoming power line to an alternate source of AC derived from the battery.

Batteries are usually low-voltage DC sources. Consequently, their energy has to be converted to AC and applied to a transformer so as to raise the voltage to the proper level for operating the computer. The conversion from DC to AC, known as inversion, is often done with high-power transistors operated as switches. The battery is connected to the primary coil of the transformer through the transistors, first in one polarity and then in the other, at a frequency identical to the normal power-line frequency—usually 50 or 60 hertz.

Inversion

The same result could in principle be obtained by operating the transistors as an oscillator powered by the battery and supplying a smoothly varying AC voltage to the transformer rather than the square pulses obtained via the switching process. This is a much less efficient procedure, however. A transistor operated as a switch is quite efficient, because in its "off" condition very little current flows at a relatively high voltage (a slight leakage through the reverse-biased collector junction), while in the "on" condition the collector-emitter voltage is very low, even though the current is large. In both conditions, the power lost is the product of the voltage and the current. Given this fact, the loss is small, because at any instant either the voltage or the current is small.

Using thyristors. Thyristors are another important class of semiconductor devices used in switching applications. The simplest of these devices is the controlled rectifier (see Figure 12), made of silicon. It may be regarded as two transistors connected to each other.

The device will start to conduct only if a suitable amount of gate current is applied. The gate current is the equivalent of the base current for the *n-p-n* transistor; the resulting larger collector current is the base current for the *p-n-p* transistor. The *p-n-p* transistor has an unusually wide base region, so its gain is small, especially at low currents. Its collector current augments the initial gate current, however. This positive feedback increases the current levels throughout the thyristor, increasing the gain of the *p-n-p* transistor, and at a certain point the combined currents through the *n-p-n* and *p-n-p* transistors are sufficient to maintain conduction through the device even if the gate current is removed. The transistors drive each other into a saturated condition such that the thyristor conducts a large current with a very low voltage drop, typically about one volt. The device remains in this conducting state for an arbitrary period and cannot be turned off under control of the gate. Conduction will cease if the anode polarity becomes negative with respect to the cathode.

Thyristors are thus well suited for operation in AC rather

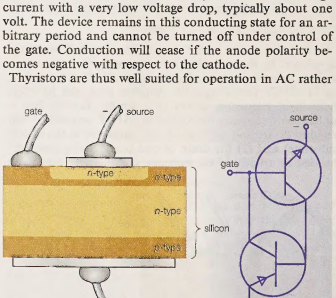

Figure 12: Cross section of an *n-p-n-p-n-p* thyristor.

than DC circuits. They can be switched on during the appropriate half-cycle of voltage (anode positive) and will automatically switch off when the polarity reverses. A single thyristor can be used as a rectifier to produce a variable DC output from a fixed AC input. Adjustment of the DC output is made by modifying the time at which the gate current is applied after the AC voltage crosses zero and becomes the right polarity for conduction. Two thyristors connected in antiparallel (*i.e.*, the anode of each is connected to the cathode of the other) form an AC switch, one thyristor being able to conduct on one half-cycle and the other on the alternate half-cycle. The amount of AC power delivered to the load may be adjusted to any level between zero and full power by appropriate timing of the gate signals to the two thyristors.

Thyristors are designed to handle both small and large amounts of power; the largest ones can withstand up to 5,000 volts in the "off" state and can conduct up to 2,000 amperes in the "on" state. Such a device is contained in an enclosure approximately 150 millimetres (6 inches) in diameter and about 30 millimetres (1 inch) thick fitted with external air- or water-cooling means. The power loss in the thyristor in such cases may be as much as 4 kilowatts, but the total amount of power handled may be up to 1,000 times as large. The efficiency is thus very high.

Other types of thyristors include those in which the gate is able to turn off the thyristor and those that can be switched on in either direction of current flow. The latter finds wide use in light-duty applications—for example, in variable-speed home appliances and light dimmers.

Light dimmers

Thyristors have many applications in industrial equipment where substantial amounts of power must be controlled electronically. These applications range from transmission of electric power over long distances, which is more efficient if done as DC rather than AC, to control of heating elements in furnaces and supplying power for electronic equipment. The very large thyristors mentioned earlier are employed in power conversion for DC transmission, both from AC to DC and vice versa.

Optoelectronic functions. Some electronic applications depend on the interactions between light and semiconductor materials mentioned in the section *Optoelectronics*. Such applications include the conversion of sunlight to electricity in solar cells. Most cells of this type consist of silicon diodes in specially designed enclosures to allow sunlight to illuminate them. Silicon is transparent to infrared light; this component of solar radiation passes through a solar cell without generating electricity. The waves of visible light, however, have enough energy to create hole-electron pairs (the mechanism that results in the absorption of the light). In the vicinity of the *p-n* junction, the holes are attracted toward the electrons on the *n*-type side, and the electrons are attracted to the holes on the *p*-type side. This constitutes a current that can be used to power small electrical appliances or to charge storage batteries.

There are special thyristors available that use light instead of a gate signal to initiate conduction. They have application in high-voltage systems wherein many thyristors in series must be employed to withstand the voltage. The practical difficulties involved in providing gate signals to all these thyristors, each at a different electrical potential, are simplified by using optical fibres (which are electrical insulators) to conduct pulses of light to the thyristors. The interaction of the light with the silicon produces carriers just as in a solar cell; these carriers provide the gate signal to switch on the thyristors.

LEDs

Light-emitting diodes (LEDs) are used in many electronic systems as visual indicators. They are made from III-V compounds related to gallium arsenide; the ones that generate red light are usually composed of gallium arsenide phosphide. The central brake light on the rear of automobiles is commonly an array of red LEDs. The red light in traffic signals is also an LED application. With the availability of brilliant, low-cost blue LEDs, it is now possible to make replacements for incandescent lightbulbs using a suitable mixture of coloured LEDs to provide the appropriate colour. These newer applications are driven by the need for greater reliability or electrical efficiency to justify the increase in cost.

Laser diodes, also made of III-V compounds, are used in digital audio and video disc players to read the minuscule tracks molded into the disc and containing the digitally recorded information. Lasers are employed because laser light can be focused into an extremely tiny spot of great brightness. The light scattered from the markings on the disc is detected by semiconductor photodiodes. (R.I.S.)

Electron tubes

Electron tubes, also called vacuum tubes or valves, are devices used in electronic circuitry to control a flow of electrons. They usually consist of a sealed glass or metal-ceramic enclosure that is used in electronic circuitry to control a flow of electrons. Among the common applications of vacuum tubes are amplification of a weak current, rectification of an alternating current (AC) to direct current (DC), generation of oscillating radio-frequency (RF) power for radio and radar, and creation of images on a television screen or computer monitor. Common types of electron tubes include magnetrons, klystrons, gyrotrons, cathode-ray tubes (such as the thyratron), photoelectric cells (also known as phototubes), and neon and fluorescent lamps.

Until the late 1950s, vacuum tubes were used in virtually every kind of electronic device—computers, radios, transmitters, components of high-fidelity sound systems, and so on. After World War II the transistor was perfected, and solid-state devices (based on semiconductors) came to be used in all applications at low power and low frequency. The common conception at first was that solid-state technology would rapidly render the electron tube obsolete. Such has not been the case, however, for each technology has come to dominate a particular frequency and power range. The higher power levels (hundreds of watts) and frequencies (above 8 gigahertz [GHz]) are dominated by electron tubes and the lower levels by solid-state devices. High power levels have always been required for radio transmitters, radar systems, and implements of electronic warfare, and microwave communications systems may require power levels of hundreds of watts. Power in these cases is frequently provided by klystrons, magnetrons, and traveling-wave tubes. Extremely high average power levels—several megawatts at frequencies above 60 GHz—are achieved by gyrotrons; these are used primarily for deep-space radars, microwave weapons, and drivers for high-energy particle accelerators.

High power levels

Vacuum tube technology continues to advance, because of a combination of device innovation, enhanced understanding through improved mathematical modeling and design, and the introduction of superior materials. The bandwidth over which electron tubes operate has more than doubled since 1990. The efficiency with which DC power is converted to RF power has increased up to 75 percent in some devices. New materials, such as diamond for dielectrics, pyrolitic graphite for collectors, and new rare-earth magnets for beam control, greatly improve the power handling and efficiency of modern electron tubes.

PRINCIPLES OF ELECTRON TUBES

An electron tube has two or more electrodes separated either by vacuum (in a vacuum tube) or by ionized gas at low pressure (in a gas tube). Its operation depends on the generation and transfer of electrons through the tube from one electrode to another. The source of electrons is the cathode, usually a metallic electrode that releases a stream of electrons (see Figure 13) by one of several mechanisms described below. Once the electrons have been emitted, their movement is controlled by an electric field, a magnetic field, or both. An electric field is established by the application of a voltage between the electrodes in the tube,

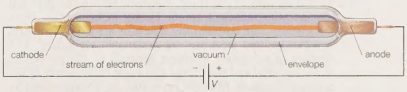

Figure 13: Elements of the simplest electron tube, the diode.

while a magnetic field may be produced outside the tube by an electromagnet or a permanent magnet. In its simplest form, an electron is attracted and accelerated by the positive electrode (a plate, or anode) and is repelled and slowed by the negative electrode (cathode). An electric field can be used to change the path of the electron stream, alter the number of flowing electrons (change the electric current), and modify their speed. The magnetic field serves primarily to control the movement of the electrons from one electrode to another.

Electron emission. In its most general sense, the emission of electrons results from directing energy in the form of heat, atomic-scale collisions, or strong electric fields to the cathode in such a way that electrons within the material are given enough kinetic energy to escape the surface. The most widely used mechanism in vacuum tubes is thermionic emission, or electron emission by application of heat.

Electronic work function

The amount of energy needed to release electrons from a given material is known as its electronic work function. It follows that the ideal materials for cathodes are those that yield the lowest electronic work function. Barium, strontium, and thorium are commonly used because of their low electronic work functions, from 1.2 to 3.5 electron volts (eV). Newer experimental materials, such as scandate (an alloy of barium and scandium oxide), have been discovered with slightly lower electronic work functions.

The anode, meanwhile, is usually made of a good conductor—such as iron, nickel, or carbon—that does not readily emit electrons at typical operating temperatures.

Thermionic emission. When solids are heated to high temperatures—about 1,000 °C (1,800 °F) or higher—electrons can be emitted from the surface. (This phenomenon was first observed by the American inventor Thomas Alva Edison in 1883 and is known as the Edison effect.) Thermionic emission is not thoroughly understood, but researchers have been able to describe it mathematically, using wave mechanics.

The most popular models rest on the Richardson-Dushman equation, derived in the 1920s, and the Langmuir-Child equation, formulated shortly thereafter. The former states that the current per unit of area, J, is given by

$$J = AT^2 e^{-W/kT}, \tag{1}$$

where k is Boltzman's constant, A is a constant of the material and its surface finish and is theoretically about 120 amperes per square centimetre per kelvin, T is the temperature of the solid, and W is its work function.

As electrons are emitted by the application of heat, an electron cloud can form in front of the cathode. Such a cloud acts to repel low-energy electrons, which return to the cathode. This limiting mechanism is aptly referred to as the space-charge-limited operation. In a device such as the diode (see Figure 13), the positive voltage applied to the anode attracts electrons from the cloud. The higher the voltage, the more electrons flow to the anode until the saturation voltage has been reached, at which point all the emitted electrons flow to the anode (known as the saturation current). In the space-charge-limited operation, the current density, J, is described by the Langmuir-Child law

Saturation current

$$J = 2.33 \times 10^{-6} \frac{V_a^{3/2}}{d^2}, \tag{2}$$

where V_a is the anode voltage and d is the distance between the anode and the cathode. The key characteristics of thermionic emission, as observed and predicted by equations (1) and (2), are the temperature-limited region and the space-charge-limited region. Much research has been concerned with the transition between the regions and with decreasing the work function of the cathode materials.

Secondary emission. When a metal or dielectric is bombarded by ions or electrons, electrons within the material may acquire sufficient kinetic energy to be emitted from the surface. The bombarding electrons are called primary, and the emitted electrons are designated secondary. The amount of secondary emission depends on the properties of the material and the energy and angle of incidence of the primary electrons. Material properties are characterized by the secondary-emission ratio, defined as the number of secondary electrons emitted per primary electron. Typically, the maximum secondary-emission ratio lies between 0.5 and 1.5 for pure metals and occurs for incident electron energies between 200 and 1,000 eV. The approximate energy distribution of secondary electrons emitted from a pure metal is skewed in such a way that about 85 percent of them have energies less than 20 eV.

Positive ion bombardment also can cause secondary emission, but it is much less efficient than electron bombardment because only a small fraction of an ion's energy can be imparted to (much lighter) electrons.

Field emission. Electron emission is influenced by an electric field applied at the cathode. For very strong electric fields, the electron emission becomes independent of temperature because the potential barrier at the surface of the cathode is made extremely narrow and electrons tunnel through the barrier even when they have low kinetic energy. Electric field strength must be about a billion volts per metre in order to cause field emissions.

Electron motion in a vacuum. Fundamental to all electron devices are the dynamics of charged particles under different electric and magnetic fields. The motion of an electron in a uniform field is given by a simple application of Isaac Newton's second law of motion, force = mass × acceleration, in which the force is exerted on the electron by an applied electric field E (measured in volts per metre). Mathematically, the equation of motion of an electron in a uniform field is given by

$$F = -eE = m\frac{dv}{dt}, \tag{3}$$

in which e is the electron charge 1.60×10^{-19} coulombs, E denotes the field in volts per metre, m is the electron mass 9.107×10^{-31} kilogram, and dv/dt denotes the rate of change of velocity, which is the electron's acceleration.

If a magnetic field is also present, the electron will experience a second force, but only when the electron is in motion. The force will then be proportional to the product of charge and the velocity component that is perpendicular to the electric field E and to the magnetic flux density B (measured in webers per square centimetre). The force will be directed perpendicular to both the electric field and the electron velocity. Thus, an electron traveling parallel to an electric field and at right angles to a uniform magnetic field will be deflected in a direction perpendicular to both fields. Because the force is constantly perpendicular to the velocity, the electron will trace out a perfectly circular trajectory and will maintain that motion at a rate called the cyclotron frequency, ω_c, given by e/mB. The circle traced out by the electron has a radius equal to mv/eB. This circular motion is exploited in many electron devices for generating or amplifying radio-frequency (RF) power.

Cyclotron frequency

An electron traveling parallel to a uniform magnetic field is unaffected by that field, but any departure from parallelism gives rise to a perpendicular component of velocity and thus a force. This force gives the nearly parallel electron a helical motion about the direction of the magnetic field, keeping it from diverging far from the parallel path. The equation of motion in any of these instances is

$$m\frac{dv}{dt} = Bev \sin \theta, \tag{4}$$

where v is the velocity of the electron in metres per second in the perpendicular direction to the plane of B and v, and q is the angle between the directions of B and v. The magnetic flux density is expressed in webers per square centimetre (1 weber per centimetre^2 = 10^4 gauss = $10^7/4\pi$ amperes per metre).

Of interest, too, is the situation in which the magnetic and electric fields are perpendicular. This configuration is used in beam-focusing devices as well as in a class of devices called magnetrons (see below). In this case the motion of the electrons is a combination of translation and circular trajectories. The resultant trajectory is a cycloid.

Equations (3) and (4) are sufficient to solve for the path and time of transit of electrons in an electron tube except that they require E and B to be known, and these may depend on the presence of electrons or ions. The currents in electron tubes are small enough in most cases that their ef-

Space charge

fect on the magnetic field is usually negligible. The cumulative effect of the electron or ion charge (called space charge) on the electric field cannot always be neglected, however, and this introduces computational difficulty unless the geometry is simple. Furthermore, the electrode currents are so dependent on space charges that the performance characteristics of electron tubes are largely determined by these charges. The electric field with or without space charge can be determined by Gauss's theorem of electrostatics, which states how electric fields are associated with charges. Basically, the rate of change of E with distance is equal to ρ/ε_0, in which ρ is the electric charge density in coulombs per metre and ε_0 is the permittivity 8.95×10^{-12} farads per metre.

The current per unit area, i, entering any surface—as that of an electrode in a tube—is the time rate of change of charge at that surface. This current is the sum of two components, one constituting the actual arrival of electrons at the electrode and the other resulting from the change of induced charge by any change of the electric field with time. Thus, i is the sum of $\rho v + \varepsilon_0 dE/dt$, where v is the electron density and dE/dt is the time-varying electric field. At low frequencies of operation or under steady conditions, the second term is not important. The contrary is true at high frequencies. This equation and the one relating the electric fields to the charges are fundamental to all high-vacuum electron tube phenomena and are sufficient to obtain theoretical solutions.

Energy transfer. The fundamental importance of a large class of electronic devices lies in their ability to amplify power. This power amplification results from the conversion of the energy stored in an external power supply to an output energy in the load circuit of the electron device. The mechanism that makes this conversion possible is the electron's change in kinetic energy as it is accelerated or decelerated by an electric field. Because energy is conserved, the RF field will increase (amplification) if the electrons lose kinetic energy, and, conversely, it will decrease if the electrons gain kinetic energy.

When a modulated electron convection current flows in an electric field of the same modulation frequency, the power transfer, P, between the field and the electron is given by

$$P = \frac{1}{2} I_c E, \tag{5}$$

where I_c is the electron convection current and E is the electric field. Both I_c and E are complex quantities; substituting their values into equation (5) and separating the real and imaginary parts yields

$$P_{\text{real}} = \frac{1}{2} I_c E \cos(\varphi_I - \varphi_E) \tag{6}$$

$$P_{\text{imag}} = \frac{1}{2} I_c E \sin(\varphi_I - \varphi_E), \tag{7}$$

in which φ_I and φ_E are the phase angles of the modulated convection current and electric field, respectively. Insight into the meaning of equations (6) and (7) may be obtained by considering a physical picture. The negative electron flow (convection current) may be supposed to induce positive charges on the electrodes from which the E field emanates. If the phase is proper, meaning that the induced charges constructively add to the current associated with the modulated E field, the E field grows. Thus, in equations (6) and (7), $P_{\text{real}} = \frac{1}{2}(I_c E)$ and P_{imag} becomes zero. Conversely, if the phases are 180° apart, P_{real} goes to zero, and $P_{\text{imag}} = \frac{1}{2}(I_c E)$ and power is transferred from the field to the electron current. In practice, different methods are used to produce density modulation in an electron beam (see below).

Convection current

COMMON TUBES AND THEIR APPLICATIONS

Many types of electron tubes are involved in RF electric power generation and amplification. Another class of electron tubes is employed for rectification and switching (thyratrons and ignitrons). Some vacuum and gas tubes are designed merely to illuminate a target, as in the case of a television tube. This discussion focuses on those electron tubes that serve as circuit elements, functioning as rectifiers, microwave RF sources, and amplifiers. Of these, the most important are the latter two types, because they constitute the technology of choice in a wide range of high-power applications. Within this category the main varieties are klystrons, magnetrons, crossed-field amplifiers, traveling-wave tubes, gyrotrons, and free-electron lasers. Special applications have given impetus to the development of microwave power sources capable of generating tremendous amounts of power (up to billions of watts). These devices are called fast-wave tubes. Some of these and other significant vacuum tubes are delineated below, as are gas tubes employed for rectification and switching.

Fast-wave tubes

Klystrons. Devices of this kind are used as amplifiers and RF signal sources at microwave frequencies (*e.g.*, in radio relay systems and for dielectric heating) and also as oscillators (*e.g.*, in continuous-wave Doppler radar systems). The klystron is a linear beam device; that is, the electron flow is in a straight line focused by an axial magnetic field. The velocities of electrons emitted from the cathode are modulated to produce a density-modulated electron beam. The principle of operation involved here can be explained in terms of a two-cavity klystron amplifier, the basic structure of which is shown in Figure 14.

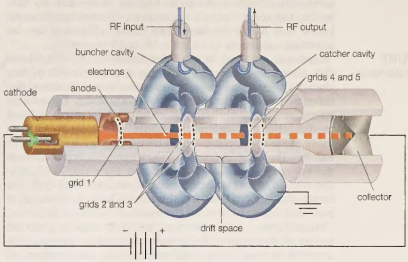

Figure 14: Two-cavity klystron.

The first grid next to the cathode controls the number of electrons in the electron beam and focuses the beam. The voltage between the cathode and the cavity resonators (the buncher and the catcher, which serve as reservoirs of electromagnetic oscillations) is the accelerating potential and is commonly referred to as the beam voltage. This voltage accelerates the DC electron beam to a high velocity before injecting it into the grids of the buncher cavity. The grids of the cavity enable the electrons to pass through, but they confine the magnetic fields within the cavity. The space between the grids is referred to as the interaction space, or gap. When the electrons traverse this space, they are subjected to RF potentials at a frequency determined by the resonant frequency of the buncher cavity and the input-signal frequency. The amplitude of the RF voltage between the grids is determined by the amplitude of the input signal. Electrons traversing the interaction space when the RF potential on grid 3 is positive with respect to grid 2 are accelerated by the field, while those crossing the gap one half-cycle later are decelerated. Essentially no energy is taken from the buncher cavity, since the average number of electrons slowed down is equal to the average number of electrons speeded up. The decelerated electrons give up energy to the fields inside the buncher cavity, while those that have been accelerated absorb energy from its fields.

Buncher cavity

Upon leaving the interaction gap, the electrons enter a region called the drift, or bunching, space, in which the electrons that were speeded up overtake the slower-moving ones. This causes the electrons to bunch and results in the density modulation of the beam, with the electron bunches representing an RF current in the beam. The catcher is located at a point where the bunching is maximum. This cavity is tuned to the same frequency as the input frequency of the buncher cavity. The power output at the

catcher is obtained by slowing down the electron bunches. If an alternating field exists at the cavity and grid 4 is positive with respect to grid 5, the electron bunches passing through the grids will be decelerated, and they will deliver energy to the output cavity. Thus, the electron bunches induce an RF current on the walls of the catcher cavity identical to the RF current in the beam. At resonance the oscillation in the cavity builds up in proper phase to retard the electron bunches. The power of the RF output is equal to the difference in the kinetic energy of the electrons averaged before and after passing the interaction gap.

The positive electrode, or collector, located beyond the catcher collects the electrons; it is designed to minimize secondary emission. (Such emission occurs because of the impact of electrons that reach the end wall.)

The klystron amplifier described above can be converted into an oscillator by employing feedback from the output cavity to the input cavity in proper phase and of sufficient amplitude to overcome the losses in the system.

The power levels of klystrons are achieved through the use of large beam voltages and currents. In simple terms, the output power P = efficiency $\times IE$, where I and E are the beam current and voltage and the efficiency is how well the DC power supplied is converted to RF power. For klystrons the efficiency can be as high as 70 percent. By collecting the spent electron beam at a potential significantly below that of the cavities, even higher efficiency can be achieved—as much as another 10 to 15 percent.

UHF television

Klystrons are used in ultrahigh-frequency (UHF) television transmissions, which operate at power levels of less than 50 kilowatts. For ground-based communications, the range of power levels is from 1 to 20 kilowatts. Pulsed klystrons are primarily used in radar and in scientific and medical linear accelerators. Some applications employ more than two cavities to obtain higher gain and more bandwidth. The power gain of the klystron is dependent on the voltage and current as well as on the number of cavities used. The larger the number of cavities employed, the larger the gain that can be obtained. There is, however, a practical limit imposed by the onset of RF instability.

Magnetrons. Magnetrons are primarily used to generate power at microwave frequencies for radar systems, microwave ovens, linear accelerators, and the creation of plasmas used for such applications as thin-film deposition and ionic etching. Within a magnetron electrons are constrained by the combined effect of a radial electrostatic field and an axial magnetic field. Magnetrons can be manufactured relatively inexpensively because they require so few parts—namely, a cathode, an anode, a tank circuit, and a magnet. A typical magnetron for microwave ovens, shown in Figure 15 in cutaway view, is described below.

The cylindrical anode structure contains a number of equally spaced cavity resonators with slots along the anode surface adjacent to the cylindrical cathode. Permanent magnets are used to provide the necessary magnetic field, which is perpendicular to the electric field between the cathode and the anode. The power output is coupled through a slot in a cavity to a waveguide that channels the microwave radiation to the cooking chamber.

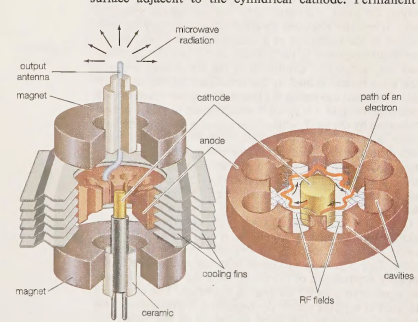

Figure 15: Typical elements of a magnetron.

As in other types of oscillators, the oscillation originates in random phenomena in the electron space charge and in the cavity resonators. The cavity oscillations produce electric fields that spread outward from the slots into the interaction space, as shown in the figure. Energy is transferred from the radial DC field to the RF field by electrons. The first orbit of an electron occurs when the RF field across the gap is in a direction to retard its motion. The resulting transfer of energy is from the electron to the tangential component of the RF field. After coming to a stop, the electron is accelerated again by the radial DC field and moves to the next cavity slot. The electron gives up most of its energy to the cavities before it finally terminates on the anode surface. There is a net delivery of energy to the cavity resonators because electrons that absorb energy from the RF field are quickly returned to the cathode. By contrast, the energy in the rotational component of motion of the electrons in the retarding RF field remains practically unaffected, and the electrons may orbit around the cathode many times.

Microwave ovens

Magnetrons have a wide range of output powers—from those used in microwave ovens for cooking, which generate 600 to 1,000 watts, to special ones capable of generating pulsed power levels up to 1,000,000 watts. The DC-to-RF power-conversion efficiency typically ranges from 50 to 85 percent.

Crossed-field amplifiers. Crossed-field amplifiers (CFA) share several characteristics with magnetrons. Both contain a cylindrical cathode coaxial with an RF structure, and each of these tubes constitutes a diode in which a magnetic field is established perpendicular to an electric field between the cathode and the anode. Another similarity is that their RF structure serves as the electron collector and must therefore be very rugged. The key difference is that CFAs use a delay line to slow down the RF, which thereby allows it to interact more efficiently with the electron stream. Thus, amplification occurs through most of one rotation of the electrons before the signal is extracted into an output waveguide. With this scheme CFAs are capable of achieving very high conversion efficiencies of more than 70 percent. Additionally, the output power of CFAs is obtained with relatively low beam voltage, two to three times lower than other devices at the same power level. The gain characteristic of CFAs is a highly nonlinear one and relatively low (one to two orders of magnitude lower) compared with other electron tubes. Bandwidths of CFAs are typically 10 to 20 percent. The advantages of the CFAs are their high efficiency, small size, and relatively low-voltage operation. They are capable of average power levels from 1 kilowatt at 10 GHz to 1 megawatt at 1 GHz.

Traveling-wave tubes. These are generally used to amplify microwave signals over broad bandwidths. The main elements of a traveling-wave tube (TWT) are (1) an electron gun, (2) a focusing structure that keeps the electrons in a linear path, (3) an RF circuit that causes RF fields to interact with the electron beam, and (4) a collector with which to collect the electrons. There are two main types of TWTs, and these are differentiated by the RF structure. One uses a slow-wave circuit called a helix for propagating the RF wave for electron-RF field interaction, and the other employs a series of staggered cavities coupled to each other for wave propagation. Each type has different characteristics and finds its use in different applications. The helix TWT is distinct from other electron tubes, as it is the only one that does not use RF cavities. Because cavities have bandwidth limitations, the coupled-cavity TWT also is bandwidth-limited to typically 10 to 20 percent. The helix TWT, however, has no particular bandwidth limitations, and, for all practical purposes, an octave bandwidth (100 percent) is attainable.

The basic helix TWT is shown schematically in Figure 16. The electron gun contains a cathode that emits electrons, and these are formed by the gun electrodes into a beam that is injected into the opening of the helix.

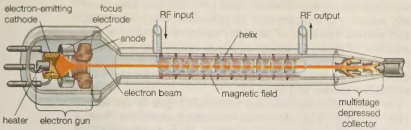

Figure 16: Basic traveling-wave tube.

Because space-charge forces tend to make the electrons diverge radially, a focusing structure is used to keep the beam at a desired diameter by causing diverging electrons to be sent toward the axis of the helix. In this manner the electron beam is maintained at the desired diameter all along the length of the helix. This is necessary because the electron-RF field interaction takes place continuously over the length of the helix within the helix diameter. In order to achieve this interaction, the diameter and pitch of the helix must be such that the RF wave traveling on the helix wire at the speed of light (about 300,000 kilometres, or 186,000 miles, per second) is slowed down in its axial travel to be in synchrony with the velocity of the electrons in the beam. The axial phase velocity of the wave is approximated by multiplying the speed of light by the ratio of the pitch to the circumference of the helix. The axial phase velocity is relatively constant over a wide range of frequencies, and this characteristic provides for the large bandwidths of helix TWTs. For typical applications the electrons travel down the helix axis at about one-tenth the speed of light. The voltage required to impart this velocity to the electrons is on the order of 10,000 volts. The RF output power and frequency required determine the actual voltage and current to be used.

Axial phase velocity

The amplifying action of the TWT occurs via a continuous interaction between the axial component of the electric field wave traveling down the centre of the helix and the electron beam moving along the axis of the helix at the same time. The electrons are continually slowed down, and their energy is transferred to the wave along the helix. The electrons tend to bunch in regions where the RF field ahead is decelerating and the field behind is accelerating. The interaction between a bunched electron beam and a helix may be viewed in terms of induced currents. The bunches of electrons induce positive charges on the helix, and these charges move in phase with the bunches. If the phase is proper, this current adds to the current associated with the RF wave flowing in the helix and causes the wave to grow. The interaction is continuous along the length of the helix, which may be up to 25 centimetres (10 inches) in length. The wave amplitude growing on the helix, in turn, causes the electrons to bunch more, and the growing bunches of electrons result in a continuous exponential growth of the helix wave with distance. Typical gains are on the order of 4 decibels per centimetre, and overall gains are 40 to 60 decibels for helix tubes of practical sizes and applications. After the electron beam has exited the helix, the electrons are decelerated by a multistage collector. By this action a large fraction of the unused beam energy can be recovered via a power supply, which thus increases the overall efficiency of the TWT. The DC-to-RF conversion efficiency of TWTs, both helix and coupled-cavity, is similar and is in the range of 50 to 75 percent, depending on the power level and bandwidth.

A special application of helix TWTs is their use as amplifiers in communications or scientific satellites and other spacecraft. The helix is ideal for this application because of its small size and weight, high efficiency, and low RF-distortion characteristics. TWTs in space have demonstrated very reliable operation, amassing tens of millions of hours of operation without failure.

Fast-wave electron tubes. Conventional electron tubes are designed to produce electron-field interaction by slowing down the RF wave to about one-tenth the speed of light. The continuing trend toward high power (more than 1 megawatt at frequencies of 60 GHz and 100 kilowatts at frequencies of 200 GHz) requires vacuum electronic devices, which operate on a different principle from that of the conventional slow-wave electron tubes. The physics of the previously described electron tubes dictates that the size of their RF elements must be in the order of the wavelength of the signal being propagated. Consequently, at frequencies above 60 GHz, dimensions and cross sections get too small for traditional tubes. A different way of creating the electron-field interaction is to allow the RF wave to propagate at essentially the speed of light by letting it pass, for example, through a section of a waveguide. Electrons used for energy transfer to the fast RF wave are bunched either by rippled magnetic fields or by RF fields that induce angular-velocity modulation. The bunched electrons give part of their energy to a properly phased microwave RF field. The advantage of fast-wave devices is that the RF circuits are large compared with the wavelength of a signal. Thus, such devices can be manufactured with large dimensions and still operate at exceedingly high frequencies—*e.g.*, 100 GHz or higher. The fast-wave tubes typically operate at very high voltages to generate the high electron velocities required for resonance conditions, which thereby permits an energy exchange to take place. In fact, it is the resonance due to the electrons in a magnetic field that determines the frequency and not a cavity structure, as in a klystron. The high-voltage AC currents used are the main reason that fast-wave devices produce exceedingly high RF power levels, up to millions of watts at very high frequencies (more than 100 GHz).

One major type of fast-wave electron tube is the gyrotron (see Figure 17). Sometimes called the cyclotron resonance maser, this device can generate megawatts of pulsed RF power at millimetre and submillimetre wavelengths. Gyrotrons make use of an energy-transfer mechanism between an electron orbiting in a magnetic field and an electromagnetic field at the cyclotron frequency. The cyclotron frequency is inversely proportional to the mass of the electron and directly proportional to its velocity and to the strength of the magnetic field. At velocities near the speed of light, the electron increases in mass (because of relativistic effects), and this increase lowers the cyclotron frequency. The interaction between the orbiting electron and the electromagnetic field is such that, if energy is given to the field, the electron loses some mass and the phase of the cyclotron wave changes. This results in a form of electron bunching analogous to the bunching in a klystron.

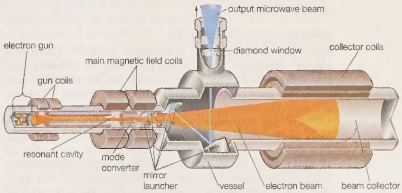

Figure 17: Typical elements of a gyrotron.

In another major type of fast-wave tube, an electromagnetic wave travels down a circular or rectangular waveguide and interacts with an undulating electron beam. The undulating motion of the electron beam is produced by a periodic magnetic field. The electrons bunch up as in the klystron process. When the bunches interact with the traveling wave, the electron energy is converted to RF energy and results in amplification. Beam voltages in these devices are on the order of 100 kilovolts, and, with electron currents of about 35 amperes, steady-state power levels of 300 watts or pulsed peak power levels of 200 kilowatts can be generated at millimetre wavelengths.

High-frequency radar

Gyrotrons and other fast-wave tubes are used in certain high-frequency (35 to 94 GHz) radar applications, in communications systems, for plasma heating in some experimental thermonuclear fusion reactors, and in industrial materials processing.

Gas electron tubes. In gas tubes the conductivity between the electrodes differs from that of a vacuum because

of the presence of a small amount of gas. Common uses of such devices are rectification and switching (*e.g.*, opening inductive energy-storage circuits, on-off modulations, and closing applications). Examples of gas tubes are the thyratron and the ignitron. Some thyratrons can handle up to 50 kilovolts, can switch thousands of amperes, and are capable of handling powers up to 40 megawatts. Thyratrons are used in radar pulse modulators, particle accelerators, and high-voltage medical equipment.

The modern gas tube is typically a coaxial four-electrode device that contains hydrogen gas at a pressure of 50–400 millitorrs (0.000066–0.00053 atmosphere). A low-voltage discharge is initiated near the cathode by the electrons that it generates, and the hydrogen gas molecules are ionized by collisions with the electrons. The electrons released by the ionized hydrogen bombard the cathode, giving rise to secondary electrons. This secondary electron emission sustains the low-voltage discharge. Some primary and secondary electrons are accelerated from the cathode and undergo more collisions with the hydrogen gas molecules. The plasma formed near the cathode can be enlarged so that contact is made with the electrode serving as the anode, and the conduction plasma path is established. The resulting current can be interrupted by means of a control grid with small apertures that pinch off the flow of plasma.

(E.N.So.)

Semiconductors

Semiconductors are a class of crystalline solids intermediate in electrical conductivity between conductors and insulators. Semiconductors are employed in the manufacture of various kinds of electronic devices, including diodes, transistors, and integrated circuits. Such devices have found wide applications because of their compactness, reliability, power efficiency, and low cost. As discrete components, they have found use in power devices, optical sensors, and light emitters, including solid-state lasers. They have a wide range of current- and voltage-handling capabilities and, more importantly, lend themselves to integration into complex but readily manufacturable microelectronic circuits. They are, and will be in the foreseeable future, the key elements for the majority of electronic systems, serving communications, signal processing, computing, and control applications in both the consumer and industrial markets.

Semiconductor materials

Solid-state materials are commonly grouped into three classes: insulators, semiconductors, and conductors. (At low temperatures some conductors, semiconductors, and insulators may become superconductors.) Figure 18 shows the conductivities σ (and the corresponding resistivities $\rho = 1/\sigma$) that are associated with some important materials in each of the three classes. Insulators, such as fused quartz and glass, have very low conductivities, on the order of 10^{-18} to 10^{-10} siemens per centimetre; and conductors, such as aluminum, have high conductivities, typically from 10^4 to 10^6 siemens per centimetre. The conductivities of semiconductors are between these extremes and are generally sensitive to temperature, illumination, magnetic fields, and minute amounts of impurity atoms. For example, the addition of about 10 atoms of boron (known as a dopant) per million atoms of silicon can increase its electrical conductivity a thousandfold (partially accounting for the wide variability shown in Figure 18).

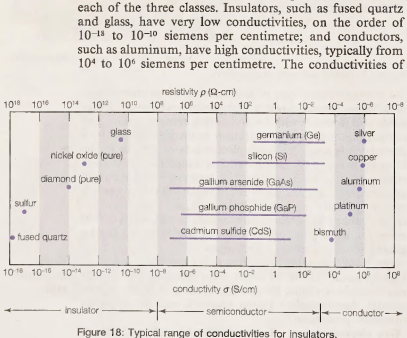

Figure 18: Typical range of conductivities for insulators, semiconductors, and conductors.

The study of semiconductor materials began in the early 19th century. The elemental semiconductors are those composed of single species of atoms, such as silicon (Si), germanium (Ge), and tin (Sn) in column IV and selenium (Se) and tellurium (Te) in column VI of the periodic table. There are, however, numerous compound semiconductors, which are composed of two or more elements. Gallium arsenide (GaAs), for example, is a binary III-V compound, which is a combination of gallium (Ga) from column III and arsenic (As) from column V. Ternary compounds can be formed by elements from three different columns—for instance, mercury indium telluride ($HgIn_2Te_4$), a II-III-VI compound. They also can be formed by elements from two columns, such as aluminum gallium arsenide ($Al_xGa_{1-x}As$), which is a ternary III-V compound, where both Al and Ga are from column III and the subscript x is related to the composition of the two elements from 100 percent Al ($x = 1$) to 100 percent Ga ($x = 0$). Pure silicon is the most important material for integrated circuit applications, and III-V binary and ternary compounds are most significant for light emission. Compound semiconductors

Prior to the invention of the bipolar transistor in 1947, semiconductors were used only as two-terminal devices, such as rectifiers and photodiodes. During the early 1950s germanium was the major semiconductor material. However, it proved unsuitable for many applications, because devices made of it exhibited high leakage currents at only moderately elevated temperatures. Since the early 1960s silicon has become the most widely used semiconductor, virtually supplanting germanium as a material for device fabrication. The main reasons are twofold: (1) silicon devices exhibit much lower leakage currents, and (2) silicon dioxide (SiO_2), which is a high-quality insulator, is easy to incorporate as part of a silicon-based device. Thus, silicon technology has become very advanced and pervasive, with silicon devices constituting more than 95 percent of all semiconductor products sold worldwide.

Many of the compound semiconductors have some specific electrical and optical properties that are superior to their counterparts in silicon. These semiconductors, especially gallium arsenide, are used mainly for optoelectronic and certain radio frequency (RF) applications.

Electronic properties

The semiconductor materials described here are single crystals; *i.e.*, the atoms are arranged in a three-dimensional periodic fashion. Part A of Figure 3 shows a simplified two-dimensional representation of an intrinsic (pure) silicon crystal that contains negligible impurities. Each silicon atom in the crystal is surrounded by four of its nearest neighbours. Each atom has four electrons in its outer orbit and shares these electrons with its four neighbours. Each shared electron pair constitutes a covalent bond. The force of attraction between the electrons and both nuclei holds the two atoms together. For isolated atoms (*e.g.*, in a gas rather than a crystal), the electrons can have only discrete energy levels. However, when a large number of atoms are brought together to form a crystal, the interaction between the atoms causes the discrete energy levels to spread out into energy bands. When there is no thermal vibration (*i.e.*, at low temperature), the electrons in an insulator or semiconductor crystal will completely fill a number of energy bands, leaving the rest of the energy bands empty. The highest filled band is called the valence band. The next band is the conduction band, which is separated from the valence band by an energy gap (much larger gaps in crystalline insulators than in semiconductors). This energy gap, also called a bandgap, is a region that designates energies that the electrons in the crystal cannot possess. Most of the important semiconductors have bandgaps in the range 0.25 to 2.5 electron volts (eV). The bandgap of silicon, for example, is 1.12 eV, and that of gallium arsenide is 1.42 Valence band

eV. In contrast, the bandgap of diamond, a good crystalline insulator, is 5.5 eV.

At low temperatures the electrons in a semiconductor are bound in their respective bands in the crystal; consequently, they are not available for electrical conduction. At higher temperatures thermal vibration may break some of the covalent bonds to yield free electrons that can participate in current conduction. Once an electron moves away from a covalent bond, there is an electron vacancy associated with that bond. This vacancy may be filled by a neighbouring electron, which results in a shift of the vacancy location from one crystal site to another. This vacancy may be regarded as a fictitious particle, dubbed a "hole," that carries a positive charge and moves in a direction opposite to that of an electron. When an electric field is applied to the semiconductor, both the free electrons (now residing in the conduction band) and the holes (left behind in the valence band) move through the crystal, producing an electric current. The electrical conductivity of a material depends on the number of free electrons and holes (charge carriers) per unit volume and on the rate at which these carriers move under the influence of an electric field. In an intrinsic semiconductor there exists an equal number of free electrons and holes. The electrons and holes, however, have different mobilities; that is to say, they move with different velocities in an electric field. For example, for intrinsic silicon at room temperature, the electron mobility is 1,500 square centimetres per volt-second ($cm^2/V{\cdot}s$)—*i.e.*, an electron will move at a velocity of 1,500 centimetres per second under an electric field of one volt per centimetre—while the hole mobility is 500 $cm^2/V{\cdot}s$. The electron and hole mobilities in a particular semiconductor generally decrease with increasing temperature.

Electron mobility

Electrical conduction in intrinsic semiconductors is quite poor at room temperature. To produce higher conduction, one can intentionally introduce impurities (typically to a concentration of one part per million host atoms). This is called doping, a process that increases conductivity despite some loss of mobility. For example, if a silicon atom is replaced by an atom with five outer electrons, such as phosphorus (see part B of Figure 3), four of the electrons form covalent bonds with the four neighbouring silicon atoms. The fifth electron becomes a conduction electron that is donated to the conduction band. The silicon becomes an *n*-type semiconductor because of the addition of the electron. The phosphorus atom is the donor. Similarly, part C of Figure 3 shows that, if an atom with three outer electrons, such as boron, is substituted for a silicon atom, an additional electron is accepted to form four covalent bonds around the boron atom, and a positively charged hole is created in the valence band. This creates a *p*-type semiconductor, with the boron constituting an acceptor.

THE *P-N* JUNCTION

If an abrupt change in impurity type from acceptors (*p*-type) to donors (*n*-type) occurs within a single crystal structure, a *p-n* junction is formed (see parts B and C of Figure 19). On the *p* side, the holes constitute the dominant carriers and so are called majority carriers. A few thermally generated electrons will also exist in the *p* side; these are termed minority carriers. On the *n* side, the electrons are the majority carriers, while the holes are the minority carriers. Near the junction is a region having no free charge carriers. This region, called the depletion layer, behaves as an insulator.

The most important characteristic of *p-n* junctions is that they rectify. Figure 19A shows the current-voltage characteristics of a typical silicon *p-n* junction. When a forward bias is applied to the *p-n* junction (*i.e.*, a positive voltage applied to the *p*-side with respect to the *n*-side, as shown in Figure 19B), the majority charge carriers move across the junction so that a large current can flow. However, when a reverse bias is applied (in Figure 19C), the charge carriers introduced by the impurities move in opposite directions away from the junction, and only a small leakage current flows. As the reverse bias is increased, the leakage current remains very small until a critical voltage is reached, at which point the current suddenly increases. This sudden increase in current is referred to as the

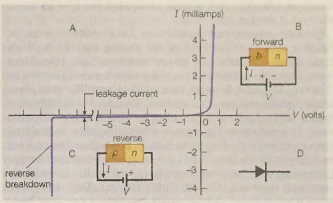

Figure 19: (A) Current-voltage characteristics of a typical silicon *p-n* junction. (B) Forward-bias and (C) reverse-bias conditions. (D) The symbol for a *p-n* junction.

junction breakdown, usually a nondestructive phenomenon if the resulting power dissipation is limited to a safe value. The applied forward voltage is typically less than one volt, but the reverse critical voltage, called the breakdown voltage, can vary from less than one volt to many thousands of volts, depending on the impurity concentration of the junction and other device parameters.

Junction breakdown

Although other junction types have been invented (including *p-n-p* and *n-p-n*), *p-n* junctions remain fundamental to semiconductor devices. For further details on applications of these basic semiconductor properties, see below *Transistors* and *Integrated circuits*.

(S.M.Sz./W.C.Ho.)

Transistors

A transistor is a semiconductor device for amplifying, controlling, and generating electrical signals. Transistors are the active components of integrated circuits, or "microchips," which often contain millions of these minuscule devices etched into their shiny surfaces. Deeply embedded in almost everything electronic, transistors have become the nerve cells of the information age.

There are typically three electrical leads in a transistor, called the emitter, the collector, and the base—or, in modern switching applications, the source, the drain, and the gate (see Figure 20). An electrical signal applied to the base (or gate) influences the semiconductor material's ability to conduct electrical current, which flows between the emitter (or source) and collector (or drain) in most applications. A voltage source such as a battery drives the current, while the rate of current flow through the transistor at any given moment is governed by an input signal at the gate—

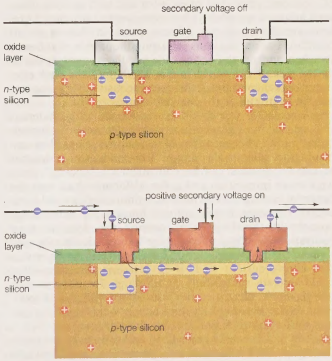

Figure 20: NMOS transistor.

much as a faucet valve is used to regulate the flow of water through a garden hose.

Hearing aids

The first commercial applications for transistors were for hearing aids and "pocket" radios during the 1950s. With their small size and low power consumption, transistors were desirable substitutes for the vacuum tubes (known as "valves" in Great Britain) then used to amplify weak electrical signals and produce audible sounds. Transistors also began to replace vacuum tubes in the oscillator circuits used to generate radio signals, especially after specialized structures were developed to handle the higher frequencies and power levels involved. Low-frequency, high-power applications, such as power-supply inverters that convert alternating current (AC) into direct current (DC), have also been transistorized. Some power transistors can now handle currents of hundreds of amperes at electric potentials over a thousand volts.

By far the most common application of transistors today is for computer memory chips—including solid-state multimedia storage devices for electronic games, cameras, and MP3 players—and microprocessors, where millions of components are embedded in a single integrated circuit. Here the voltage applied to the gate electrode, generally a few volts or less, determines whether current can flow from the transistor's source to its drain. In this case the transistor operates as a switch: if a current flows, the circuit involved is on, and if not, it is off. These two distinct states, the only possibilities in such a circuit, correspond respectively to the binary 1s and 0s employed in digital computers. Similar applications of transistors occur in the complex switching circuits used throughout modern telecommunications systems. The potential switching speeds of these transistors now exceed a gigahertz, or more than a billion on-and-off cycles per second.

DEVELOPMENT OF TRANSISTORS

The transistor was invented in 1947–48 by three American physicists, John Bardeen, Walter H. Brattain, and William B. Shockley, at the American Telephone and Telegraph Company's Bell Laboratories. The transistor proved to be a viable alternative to the electron tube and, by the late 1950s, supplanted the latter in many applications. Its small size, low heat generation, high reliability, and low power consumption made possible a breakthrough in the miniaturization of complex circuitry. During the late 1960s and '70s, transistors were incorporated into integrated circuits, in which a multitude of components (*e.g.*, diodes, resistors, and capacitors) are formed on a single "chip" of semiconductor material.

Motivation and early radar research. Electron tubes are bulky and fragile, and they consume large amounts of power to heat their cathode filaments and generate streams of electrons; also, they often burn out after several thousand hours of operation. Electromechanical switches, or relays, are slow and can become stuck in the on or off position. For applications requiring thousands of tubes or switches, such as the nationwide telephone systems developing around the world in the 1940s and the first electronic digital computers, this meant constant vigilance was needed to minimize the inevitable breakdowns.

An alternative was found in semiconductors, materials such as silicon or germanium whose electrical conductivity lies midway between that of insulators such as glass and conductors such as aluminum. The conductive properties of semiconductors can be controlled by "doping" them with select impurities, and a few visionaries had seen the potential of such devices for telecommunications and computers. However, it was military funding for radar development in the 1940s that opened the door to their realization. The "superheterodyne" electronic circuits used to detect radar waves required a diode rectifier—a device that allows current to flow in just one direction—that could operate successfully at ultrahigh frequencies over one gigahertz. Electron tubes just did not suffice, and solid-state diodes based on existing copper-oxide semiconductors were also much too slow for this purpose.

Super-heterodyne

Crystal rectifiers based on silicon and germanium came to the rescue. In these devices a tungsten wire was jabbed into the surface of the semiconductor material, which was doped with tiny amounts of impurities, such as boron or phosphorus. The impurity atoms assumed positions in the material's crystal lattice, displacing silicon (or germanium) atoms and thereby generating tiny populations of charge carriers (such as electrons) capable of conducting usable electrical current. Depending on the nature of the charge carriers and the applied voltage, a current could flow from the wire into the surface or vice-versa, but not in both directions. Thus, these devices served as the much-needed rectifiers operating at the gigahertz frequencies required for detecting rebounding microwave radiation in military radar systems. By the end of World War II, millions of crystal rectifiers were being produced annually by such American manufacturers as Sylvania and Western Electric.

Innovation at Bell Labs. Executives at Bell Labs had recognized that semiconductors might lead to solid-state alternatives to the electron-tube amplifiers and electromechanical switches employed throughout the nationwide Bell telephone system. In 1936 the new director of research at Bell Labs, Mervin Kelly, began recruiting solid-state physicists. Among his first recruits was William B. Shockley, who proposed a few amplifier designs based on copper-oxide semiconductor materials then used to make diodes. With the help of Walter H. Brattain, an experimental physicist already working at Bell Labs, he even tried to fabricate a prototype device in 1939, but it failed completely. Semiconductor theory could not yet explain exactly what was happening to electrons inside these devices, especially at the interface between copper and its oxide. Compounding the difficulty of any theoretical understanding was the problem of controlling the exact composition of these early semiconductor materials.

With the close of World War II, Kelly reorganized Bell Labs and created a new solid-state research group headed by Shockley. The postwar search for a solid-state amplifier began in April 1945 with Shockley's suggestion that silicon and germanium semiconductors could be used to make a field-effect amplifier (see below *Integrated circuits: Field-effect transistors*). He reasoned that an electric field from a third electrode could increase the conductivity of a sliver of semiconductor material just beneath it and thereby allow usable current to flow through the sliver. But attempts to fabricate such a device by Brattain and others in Shockley's group again failed. The following March, John Bardeen, a theoretical physicist whom Shockley had hired for his group, offered a possible explanation. Perhaps electrons drawn to the semiconductor surface by the electric field were blocking the penetration of this field into the bulk material, thereby preventing it from influencing the conductivity.

Surface-state electrons

Bardeen's conjecture spurred a basic research program at Bell Labs into the behaviour of these "surface-state" electrons. While studying this phenomenon in November 1947, Brattain stumbled upon a way to neutralize their blocking effect and permit the applied field to penetrate deep into the semiconductor material. Working closely together over the next month, Bardeen and Brattain invented the first successful semiconductor amplifier, called the point-contact transistor, on December 16, 1947. Similar to the World War II crystal rectifiers, this weird-looking device (see Figure 1) had not one but two closely spaced metal wires jabbing into the surface of a semiconductor—in this case, germanium. The input signal on one of these wires (the emitter) boosted the conductivity of the germanium beneath both of them, thus modulating the output signal on the other wire (the collector). Observers present at a demonstration of this device the following week could hear amplified voices in the earphones that it powered. Shockley later called this invention a "magnificent Christmas present" for the farsighted company, which had supported the research program that made this breakthrough.

Not to be outdone by members of his own group, Shockley conceived yet another way to fabricate a semiconductor amplifier the very next month, on January 23, 1948. His junction transistor was basically a three-layer sandwich of germanium or silicon in which the adjacent layers would be doped with different impurities to induce distinct electrical characteristics. An input signal entering the middle layer—the "meat" of the semiconductor sandwich—determined

how much current flowed from one end of the device to the other under the influence of an applied voltage. Shockley's device is often called the bipolar junction transistor because its operation requires that the negatively charged electrons and their positively charged counterparts (the holes corresponding to an absence of electrons in the crystal lattice) coexist briefly in the presence of one another.

Bipolar junction transistor

The name *transistor,* a combination of *transfer* and *resistor,* was coined for these devices in May 1948 by Bell Labs electrical engineer John Robinson Pierce, who was also a science-fiction author in his spare time. A month later Bell Labs announced the revolutionary invention in a press conference held at its New York City headquarters, heralding Bardeen, Brattain, and Shockley as the three coinventors of the transistor. The three were eventually awarded the Nobel Prize for Physics for their invention.

Although the point-contact transistor was the first transistor invented, it faced a difficult gestation period and was eventually used only in a switch made for the Bell telephone system. Manufacturing them reliably and with uniform operating characteristics proved a daunting problem, largely because of hard-to-control variations in the metal-to-semiconductor point contacts.

Shockley had foreseen these difficulties in the process of conceiving the junction transistor, which he figured would be much easier to manufacture. But it still required more than three years, until mid-1951, to resolve its own development problems. Bell Labs scientists, engineers, and technicians first had to find ways to make ultrapure germanium and silicon, form large crystals of these elements, dope them with narrow layers of the required impurities, and attach delicate wires to these layers to serve as electrodes. In July 1951 Bell Labs announced the successful invention and development of the junction transistor, this time with only Shockley in the spotlight.

Commercialization. Commercial transistors began to roll off production lines during the 1950s, after Bell Labs licensed the technology of their production to other companies, including General Electric, Raytheon, RCA, Sylvania, and Transitron Electronics. Transistors found ready applications in lightweight devices such as hearing aids and portable radios. Texas Instruments Inc., working with the Regency Division of Industrial Development Engineering Associates, manufactured the first transistor radio in late 1954. Selling for $49.95, the Regency TR-1 employed four germanium junction transistors in a multistage amplifier of radio signals. The very next year a new Japanese company, Sony, introduced its own transistor radio and began to corner the market for this and other transistorized consumer electronics.

First transistor radio

Transistors also began replacing vacuum tubes in the digital computers manufactured by IBM, Control Data, and other companies. "It seems to me that in these robot brains the transistor is the ideal nerve cell," Shockley had observed in a 1949 radio interview. "The advantage of the transistor is that it is inherently a small-size and low-power device," noted Bell Labs circuit engineer Robert Wallace early in the 1950s. "This means you can pack a large number of them in a small space without excessive heat generation and achieve low propagation delays. And that's what you need for logic applications. The significance of the transistor is not that it can replace the tube but that it can do things the vacuum tube could never do!" After 1955 IBM started purchasing germanium transistors from Texas Instruments to employ in its computer circuits. By the end of the 1950s, bipolar junction transistors had almost completely replaced electron tubes in computer applications.

Silicon transistors. During the 1950s, meanwhile, scientists and engineers at Bell Labs and Texas Instruments were developing advanced technologies needed to produce silicon transistors. Because of its higher melting temperature and greater reactivity, silicon was more difficult to work with than germanium, but it offered major prospects for better performance, especially in switching applications. Germanium transistors make leaky switches; substantial leakage currents can flow when these devices are supposedly in their off state. Silicon transistors have far less leakage. In 1954 Texas Instruments produced the first commercially available silicon junction transistors and quickly dominated this new market—especially for military applications, in which their high cost was of little concern.

In the mid-1950s Bell Labs focused its transistor-development efforts around new diffusion technologies, in which very narrow semiconductor layers—with thicknesses measured in microns—are prepared by diffusing impurity atoms into the semiconductor surface from a hot gas. Inside a diffusion furnace the impurity atoms penetrate more readily into the silicon or germanium surface; their penetration depth is controlled by varying the density, temperature, and pressure of the gas as well as the processing time. For the first time, diodes and transistors produced by these diffusion implantation processes functioned at frequencies above 100 megahertz (100 million cycles per second). These diffused-base transistors could be used in receivers and transmitters for FM radio and television, which operate at such high frequencies.

Another important breakthrough occurred at Bell Labs in 1955, when Carl Frosch and Link Derick developed a means of producing a glassy silicon dioxide outer layer on the silicon surface during the diffusion process. This layer offered transistor producers a promising way to protect the silicon underneath from further impurities once the diffusion process was finished and the desired electrical properties had been established.

Texas Instruments, Fairchild Semiconductor Corporation, and other companies took the lead in applying these diffusion technologies to the large-scale manufacture of transistors. At Fairchild, physicist Jean Hoerni developed the planar manufacturing process, whereby the various semiconductor layers and their sensitive interfaces are embedded beneath a protective silicon dioxide outer layer. The company was soon making and selling planar silicon transistors, largely for military applications. Led by Robert Noyce and Gordon E. Moore, Fairchild's scientists and engineers extended this revolutionary technique to the manufacture of integrated circuits.

Planar manufacturing process

In the late 1950s Bell Labs researchers developed ways to use the new diffusion technologies to realize Shockley's original 1945 idea of a field-effect transistor (FET). To do so, they had to overcome the problem of surface-state electrons, which would otherwise have blocked external electric fields from penetrating into the semiconductor. They succeeded by carefully cleaning the silicon surface and growing a very pure silicon dioxide layer on it. This approach reduced the number of surface-state electrons at the interface between the silicon and oxide layers, permitting fabrication of the first successful field-effect transistor in 1960 at Bell Labs—which, however, did not pursue its development any further.

Refinements of the FET design by other companies, especially RCA and Fairchild, resulted in the metal-oxide-semiconductor field-effect transistor (MOSFET) during the early 1960s. The key problems to be solved were the stability and reliability of these MOS transistors, which relied upon interactions occurring at or near the sensitive silicon surface rather than deep inside. The two firms began to make MOS transistors commercially available in late 1964.

In early 1963 Frank Wanlass at Fairchild developed the complementary MOS (CMOS) transistor circuit, based on a pair of MOS transistors (see Figure 21). This approach eventually proved ideal for use in integrated circuits because of its simplicity of production and very low power dissipation during standby operation. Stability problems continued to plague MOS transistors, however, until researchers at Fairchild developed solutions in the mid-1960s. By the end of the decade, MOS transistors were beginning to displace bipolar junction transistors in microchip manufacturing. Since the late 1980s CMOS has been the technology of choice for digital applications, while bipolar transistors are now used primarily for analog and microwave devices.

TRANSISTOR PRINCIPLES

The *p-n* junction. The operation of junction transistors, as well as most other semiconductor devices, depends heavily on the behaviour of electrons and holes at the interface between two dissimilar layers, known as a *p-n* junction. Discovered in 1940 by Bell Labs electrochemist

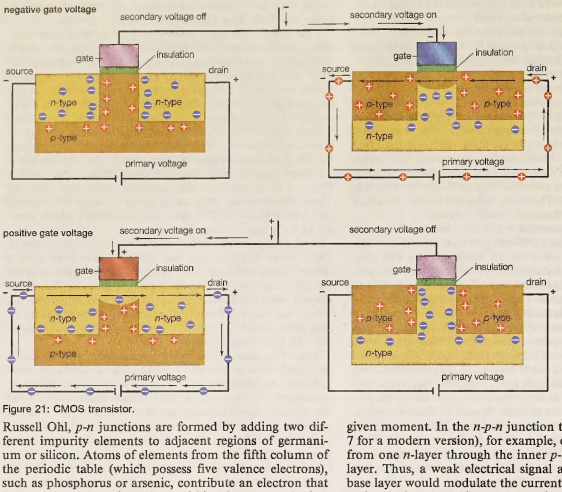

Figure 21: CMOS transistor.

Russell Ohl, *p-n* junctions are formed by adding two different impurity elements to adjacent regions of germanium or silicon. Atoms of elements from the fifth column of the periodic table (which possess five valence electrons), such as phosphorus or arsenic, contribute an electron that has no natural resting place within the crystal lattice. These excess electrons are therefore loosely bound and relatively free to roam about, acting as charge carriers that can conduct electrical current. Atoms of elements from the third column (which have three valence electrons), such as boron or aluminum, induce a deficit of electrons when added as impurities, effectively creating "holes" in the lattice. These positively charged, quantum mechanical entities are also fairly free to roam around and conduct electricity. Under the influence of an electric field, the electrons and holes move in opposite directions. During and immediately after World War II, chemists and metallurgists at Bell Labs perfected techniques of adding impurities to high-purity silicon and germanium to induce the desired electron-rich layer (known as the *n*-layer) and the electron-poor layer (known as the *p*-layer) in these semiconductors.

Rectifiers

A *p-n* junction acts as a rectifier, similar to the old point-contact crystal rectifiers, permitting easy flow of current in only a single direction. If no voltage is applied across the junction, electrons and holes will gather on opposite sides of the interface to form a depletion layer that will act as an insulator between the two sides (see Figure 5). A negative voltage applied to the *n*-layer will drive the excess electrons within it toward the interface, where they will combine with the positively charged holes attracted there by the electric field. Current will then flow easily (see Figure 6). If instead a positive voltage is applied to the *n*-layer, the resulting electric field will draw electrons away from the interface, so combinations of them with holes will occur much less often. In this case current will not flow (other than tiny leakage currents). Thus, electricity will flow in only one direction through a *p-n* junction.

Junction transistors. Shortly after his colleagues John Bardeen and Walter H. Brattain invented their point-contact device, Bell Labs physicist William B. Shockley recognized that these rectifying characteristics might also be used in making a junction transistor. In a 1949 paper Shockley explained the physical principles behind the operation of these junctions and showed how to use them in a three-layer—*n-p-n* or *p-n-p*—device that could act as a solid-state amplifier or switch. Electric current would flow from one end to the other, with the voltage applied to the inner layer governing how much current rushed by at any given moment. In the *n-p-n* junction transistor (see Figure 7 for a modern version), for example, electrons would flow from one *n*-layer through the inner *p*-layer to the other *n*-layer. Thus, a weak electrical signal applied to the inner, base layer would modulate the current flowing through the entire device. For this current to flow, some of the electrons would have to survive briefly in the presence of holes; in order to reach the second *n*-layer, they could not all combine with holes in the *p*-layer. Such bipolar operation was not at all obvious when Shockley first conceived his junction transistor. Experiments with increasingly pure crystals of silicon and germanium showed that it indeed occurred, making bipolar junction transistors possible.

Bipolar operation

To achieve bipolar operation, it also helps that the base layer be narrow, so that electrons (in *n-p-n* transistors) and holes (in *p-n-p*) do not have to travel very far in the presence of their opposite numbers. Narrow base layers also promote high-frequency operation of junction transistors: the narrower the base, the higher the operating frequency. That is a major reason why there was so much interest in developing diffused-base transistors during the 1950s, as described above in the section *Silicon transistors*. Their microns-thick bases permitted transistors to operate above 100 megahertz (100 million cycles per second) for the first time.

MOS-type transistors. A similar principle applies to metal-oxide-semiconductor (MOS) transistors, but here it is the distance between source and drain that largely determines the operating frequency. In an *n*-channel MOS (NMOS) transistor (see Figure 20), for example, the source and the drain are two *n*-type regions that have been established in a piece of *p*-type semiconductor, usually silicon. Except for the two points at which metal leads contact these regions, the entire semiconductor surface is covered by an insulating oxide layer. The metal gate, usually aluminum, is deposited atop the oxide layer just above the gap between source and drain. If there is no voltage (or a negative voltage) upon the gate, the semiconductor material beneath it will contain excess holes, and very few electrons will be able to cross the gap, because one of the two *p-n* junctions will block their path. Therefore, no current will flow in this configuration—other than unavoidable leakage currents. If the gate voltage is instead positive, an electric field will penetrate through the oxide layer and attract electrons into the silicon layer (often called the inversion layer) directly beneath the gate. Once this voltage exceeds a specific threshold value, electrons will begin flowing easily between source and drain. The transistor turns on.

Analogous behaviour occurs in a *p*-channel MOS transis-

tor, in which the source and the drain are *p*-type regions formed in *n*-type semiconductor material. Here a negative voltage above a threshold induces a layer of holes (instead of electrons) beneath the gate and permits a current of them to flow from source to drain. For both *n*-channel and *p*-channel MOS (also called NMOS and PMOS) transistors, the operating frequency is largely governed by the speed at which the electrons or holes can drift through the semiconductor material divided by the distance from source to drain. Because electrons have mobilities through silicon that are about three times higher than holes, NMOS transistors can operate at substantially higher frequencies than PMOS transistors. Small separations between source and drain also promote high-frequency operation, and extensive efforts have been devoted to reducing this distance.

In the 1960s Frank Wanlass of Fairchild Semiconductor recognized that combinations of an NMOS and a PMOS transistor would draw extremely little current in standby operation—just the tiny, unavoidable leakage currents.

CMOS

These CMOS, or complementary metal-oxide-semiconductor, transistor circuits consume significant power only when the gate voltage exceeds some threshold and a current flows from source to drain (see Figure 21). Thus, they can serve as very low-power devices, often a million times lower than the equivalent bipolar junction transistors. Together with their inherent simplicity of fabrication, this feature of CMOS transistors has made them the natural choice for manufacturing microchips, which today cram millions of transistors into a surface area smaller than a fingernail. In such cases the waste heat generated by the component's power consumption must be kept to an absolute minimum, or the chips will simply melt.

Field-effect transistors. Another kind of unipolar transistor, called the metal-semiconductor field-effect transistor (MESFET), is particularly well suited for microwave and other high-frequency applications because it can be manufactured from semiconductor materials with high electron mobilities that do not support an insulating oxide surface layer. These include compound semiconductors such as germanium-silicon and gallium arsenide. A MESFET is built much like a MOS transistor (see Figure 22) but with no oxide layer between the gate and the underlying conduction channel. Instead, the gate makes a direct, rectifying contact with the channel, which is generally a thin layer of *n*-type semiconductor supported underneath by an insulating substrate. A negative voltage on the gate induces a depletion layer just beneath it that restricts the flow of electrons between source and drain. The device acts like a voltage-controlled resistor; if the gate voltage is large enough, it can block this flow almost completely. By contrast, a positive voltage on the gate encourages electrons to traverse the channel.

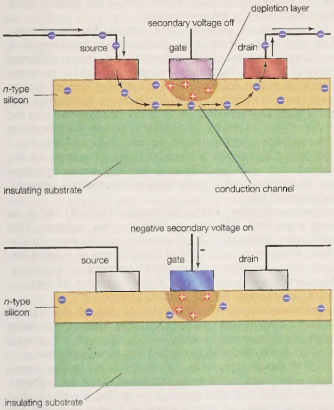

Figure 22: In a metal-semiconductor field-effect transistor (MESFET), current is normally on (used to represent "true" or "1"). A secondary voltage is applied to the gate to deplete charge carriers beneath it, thereby pinching off the current, or changing the state to off ("false" or "0").

To improve MESFET performance even further, advanced devices known as heterojunction field-effect transistors have been developed, in which *p*-*n* junctions are established between two slightly dissimilar semiconductor materials, such as gallium arsenide and aluminum gallium arsenide. By properly controlling the impurities in the two substances, a high-conductivity channel can be formed at their interface, promoting the flow of electrons through it. If one semiconductor is a high-purity material, its electron mobility can be large, resulting in a high operating frequency for this kind of transistor. (The electron mobility of gallium arsenide, for example, is five times that of silicon.) Heterojunction MESFETs are increasingly used for microwave applications such as cellular telephone systems.

TRANSISTORS AND MOORE'S LAW

In 1965, four years after Fairchild Semiconductor Corporation and Texas Instruments Inc. marketed their first integrated circuits, Fairchild research director Gordon E. Moore made a prediction in a special issue of *Electronics* magazine. Observing that the total number of components in these circuits had roughly doubled each year, he blithely extrapolated this annual doubling to the next decade, estimating that microcircuits of 1975 would contain an astounding 65,000 components per chip.

History proved Moore correct. His bold extrapolation has since become enshrined as Moore's law—though its doubling period was lengthened to 18 months in the mid-1970s (see Figure 2). What has made this dramatic explosion in circuit complexity possible is the steadily shrinking size of transistors over the decades. Measured in millimetres in the late 1940s, the dimensions of a typical transistor are now more commonly expressed in tenths of a micron, a reduction factor of over 10,000. Submicron transistor features were attained during the 1980s, when dynamic random-access memory (DRAM) chips began offering megabit storage capacities. At the dawn of the 21st century, these features approached 0.1 micron across, which allowed the manufacture of gigabit memory chips and microprocessors that operate at gigahertz frequencies.

DRAM

As the size of transistors has shrunk, their cost has plummeted correspondingly from tens of dollars apiece to thousandths of a penny. As Moore was fond of saying, every year more transistors are produced than raindrops over California, and it costs less to make one than to print a single character on this page. They are by far the most common human artifact on the planet. Deeply embedded in everything electronic, transistors permeate modern life almost as thoroughly as molecules permeate matter. Cheap, portable, and reliable equipment based on this remarkable device can be found in almost any village and hamlet in the world. This tiny invention, by making possible the information age, has transformed the world into a truly global society, making it a far more intimately connected place than ever before. (E.M.Ri.)

Integrated circuits

An integrated circuit (IC) is an assembly of electronic components, fabricated as a single unit, in which miniaturized active devices (*e.g.*, transistors and diodes) and passive devices (*e.g.*, capacitors and resistors) and their interconnections are built up on a thin substrate of semiconductor material (typically silicon). The resulting circuit is thus a small monolithic "chip," which may be as small as a few square centimetres or only a few square millimetres. The individual circuit components are generally microscopic in size.

Integrated circuits have their origin in the invention of the transistor in 1947 by William B. Shockley and his team at the American Telephone and Telegraph Company's Bell Laboratories. Shockley's team (including John Bardeen

and Walter H. Brattain) found that, under the right circumstances, electrons would form a barrier at the surface of certain crystals, and they learned to control the flow of electricity through the crystal by manipulating this barrier. Controlling electron flow through a crystal allowed the team to create a device that could perform certain electrical operations, such as signal amplification, that were previously done by vacuum tubes. They named this device a transistor, from a combination of the words *transfer* and *resistor* (see Figure 1). The study of methods of creating electronic devices using solid materials became known as solid-state electronics. Solid-state devices proved to be much sturdier, easier to work with, more reliable, much smaller, and less expensive than vacuum tubes. Using the same principles and materials, engineers soon learned to create other electrical components, such as resistors and capacitors. Now that electrical devices could be made so small, the largest part of a circuit was the awkward wiring between the devices.

IC inventors

In 1958 Jack Kilby of Texas Instruments, Inc., and Robert Noyce of Fairchild Semiconductor Corporation independently thought of a way to reduce circuit size further. They laid very thin paths of metal (usually aluminum or copper) directly on the same piece of material as their devices. These small paths acted as wires. With this technique an entire circuit could be "integrated" on a single piece of solid material and an integrated circuit (IC) thus created. ICs can contain hundreds of thousands of individual transistors on a single piece of material the size of a pea. Working with that many vacuum tubes would have been unrealistically awkward and expensive. The invention of the integrated circuit made technologies of the information age feasible. ICs are now used extensively in all walks of life, from cars to toasters to amusement park rides.

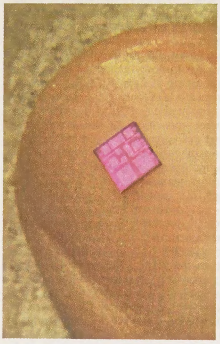

Figure 23: An integrated circuit, or silicon chip, shown on a fingernail.
Charles Falco/Photo Researchers

BASIC IC TYPES

Analog versus digital circuits. Analog, or linear, circuits typically use only a few components and are thus some of the simplest types of ICs. Generally, analog circuits are connected to devices that collect signals from the environment or send signals back to the environment. For example, a microphone converts fluctuating vocal sounds into an electrical signal of varying voltage. An analog circuit then modifies the signal in some useful way—such as amplifying it or filtering it of undesirable noise. Such a signal might then be fed back to a loudspeaker, which would reproduce the tones originally picked up by the microphone. Another typical use for an analog circuit is to control some device in response to continual changes in the environment. For example, a temperature sensor sends a varying signal to a thermostat, which can be programmed to turn an air conditioner, heater, or oven on and off once the signal has reached a certain value.

A digital circuit, on the other hand, is designed to accept only voltages of specific given values. A circuit that uses only two states is known as a binary circuit. Circuit design with binary quantities, "on" and "off" representing 1 and 0 (*i.e.*, true and false), uses the logic of Boolean algebra. The three basic logic functions—NOT, AND, and OR—together with their truth tables are given in Figure 24. (Arithmetic is also performed in the binary number system employing Boolean algebra.) These basic elements are combined in the design of ICs for digital computers and associated devices to perform the desired functions.

Boolean algebra

A	0	1
$\bar{A}$	1	0

A	0	0	1	1
B	0	1	0	1
A • B	0	0	0	1

A	0	0	1	1
B	0	1	0	1
A + B	0	1	1	1

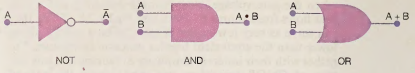

Figure 24: The logic symbol, its corresponding function, and the truth table defining the operation are shown. The NOT function inverts the signal (*i.e.*, a 1 becomes a 0 and a 0 becomes a 1). The AND function generates a true, or 1, if both inputs are 1; otherwise the output is false, or 0. The OR function generates a 1, or true, if either input is a 1, or true, value.

Microprocessor circuits. Microprocessors are the most complicated ICs. They are composed of millions of transistors that have been configured as thousands of individual digital circuits, each of which performs some specific logic function. A microprocessor is built entirely of these logic circuits synchronized to each other.

Just like a marching band, the circuits perform their logic function only on direction by the bandmaster. The bandmaster in a microprocessor, so to speak, is called the clock. The clock is a signal that quickly alternates between two logic states. Every time the clock changes state, every logic circuit in the microprocessor does something. Calculations can be made very quickly, depending on the speed ("clock frequency") of the microprocessor.

Microprocessor clock

Microprocessors contain some circuits, known as registers, that store information. Registers are predetermined memory locations. Each processor has many different types of registers. Permanent registers are used to store the preprogrammed instructions required for various operations (such as addition and multiplication). Temporary registers store numbers that are to be operated on and also the result. Other examples of registers include the "program counter," the "stack pointer," and the "address" register.

Microprocessors can perform millions of operations per second on data. In addition to computers, microprocessors are common in video game systems, televisions, cameras, and automobiles.

Memory circuits. Microprocessors typically have to store more data than can be held in a few registers. This additional information is relocated to special memory circuits. Memory is composed of dense arrays of parallel circuits that use their voltage states to store information. Memory also stores the temporary sequence of instructions, or program, for the microprocessor.

Manufacturers continually strive to reduce the size of memory circuits—to increase capability without increasing space. Smaller components also typically use less power, operate more efficiently, and cost less to manufacture.

Digital signal processors. A signal is an analog waveform—anything in the environment that can be captured electronically. A digital signal is an analog waveform that has been converted into a series of binary numbers for quick manipulation. As the name implies, a digital signal processor (DSP) processes signals digitally, as patterns of 1s and 0s. For instance, using an analog-to-digital converter, commonly called an A-to-D or A/D converter, a recording

DSP

of someone's voice can be converted into digital 1s and 0s. The digital representation of the voice can then be modified by a DSP using complex mathematical formulas. For example, the DSP algorithm in the circuit may be configured to recognize gaps between spoken words as background noise and digitally remove ambient noise from the waveform. Finally, the processed signal can be converted back (by a D/A converter) into an analog signal for listening. Digital processing can filter out background noise so fast that there is no discernible delay and the signal appears to be heard in "real time." For instance, such processing enables "live" television broadcasts to focus on a quarterback's signals in an American gridiron football game.

Digital effects

DSPs are also used to produce digital effects on live television. For example, the yellow marker lines displayed during the football game are not really on the field; a DSP adds the lines after the cameras shoot the picture but before it is broadcast. Similarly, some of the advertisements seen on stadium fences and billboards during televised sporting events are not really there.

Application-specific ICs. An application-specific IC (ASIC) can be either a digital or an analog circuit. As their name implies, ASICs are not reconfigurable; they perform only one specific function. For example, a speed controller IC for a remote control car is hard-wired to do one job and could never become a microprocessor. An ASIC does not contain any ability to follow alternate instructions.

Radio-frequency ICs. Radio-frequency ICs (RFICs) are rapidly gaining importance in cellular telephones and pagers. RFICs are analog circuits that usually run in the frequency range of 900 MHz to 2.4 GHz (900 million hertz to 2.4 billion hertz). They are usually thought of as ASICs even though some may be configurable for several similar applications.

In most semiconductor circuits operating above 500 MHz, the electronic components and their connecting paths interfere with each other in unusual ways. Engineers must use special design techniques to deal with the physics of high-frequency microelectronic interactions.

Microwave monolithic ICs. A special type of RFIC is known as a microwave monolithic IC (MMIC). These circuits run in the 2.4- to 20-GHz range, or microwave frequencies, and are used in radar systems, in satellite communications, and as power amplifiers for cellular telephones.

Just as sound travels faster through water than through air, electron velocity is different through each type of semiconductor material. Silicon offers too much resistance for microwave-frequency circuits, and so the compound gallium arsenide (GaAs) is often used for MMICs. Unfortunately, GaAs is mechanically much less sound than silicon. It breaks easily, so GaAs wafers are usually much more expensive to build than silicon wafers.

BASIC SEMICONDUCTOR DESIGN

Any material can be classified as one of three types: conductor, insulator, or semiconductor. A conductor (such as copper or salt water) can easily conduct electricity because it has an abundance of free electrons. An insulator (such as ceramic or dry air) conducts electricity very poorly because it has few or no free electrons. A semiconductor (such as silicon or gallium arsenide) is somewhere between a conductor and an insulator. It is capable of conducting some electricity, but not much.

Doping silicon. Most ICs are made of silicon, which is abundant in ordinary beach sand. Pure crystalline silicon, as with other semiconducting materials, has a very high resistance to electrical current at normal room temperature. However, with the addition of certain impurities, known as dopants, the silicon can be made to conduct usable currents. In particular, the doped silicon can be used as a switch, turning current off and on as desired.

The process of introducing impurities is known as doping or implantation. Depending on a dopant's atomic structure, the result of implantation will be either an *n*-type (negative) or a *p*-type (positive) semiconductor. An *n*-type semiconductor results from implanting dopant atoms that have more electrons in their outer (bonding) shell than silicon, as shown in Figure 3. The resulting semiconductor crystal contains excess, or free, electrons that are available for conducting current. A *p*-type semiconductor results from implanting dopant atoms that have fewer electrons in their outer shell than silicon. The resulting crystal contains "holes" in its bonding structure where electrons would normally be located. In essence, such holes can move through the crystal conducting positive charges.

The *p-n* junction. A *p*-type or an *n*-type semiconductor is not very useful on its own. However, joining these opposite materials creates what is called a *p-n* junction (see Figure 5). A *p-n* junction forms a barrier to conduction between the materials. Although the electrons in the *n*-type material are attracted to the holes in the *p*-type material, the electrons are not normally energetic enough to overcome the intervening barrier. However, if additional energy is provided to the electrons in the *n*-type material, they will be capable of crossing the barrier into the *p*-type material—and current will flow. This additional energy can be supplied by applying a positive voltage to the *p*-type material, as shown in the figure. The negatively charged electrons will then be highly attracted to the positive voltage across the junction.

Forward and reverse bias

A *p-n* junction that conducts electricity when energy is added to the *n* material is called forward-biased because the electrons move forward into the holes. If voltage is applied in the opposite direction—a positive voltage connected to the *n* side of the junction—no current will flow. The electrons in the *n* material will still be attracted to the positive voltage, but the voltage will now be on the same side of the barrier as the electrons. In this state a junction is said to be reverse-biased. Since *p-n* junctions conduct electricity in only one direction, they are a type of diode. Diodes are essential building blocks of semiconductor switches.

Field-effect transistors. Bringing a negative voltage close to the centre of a long strip of *n*-type material will repel nearby electrons in the material and thus form holes—that is, transform some of the strip in the middle to *p*-type material. This change in polarity is called the field effect. (See Figure 25.) While the voltage is being applied,

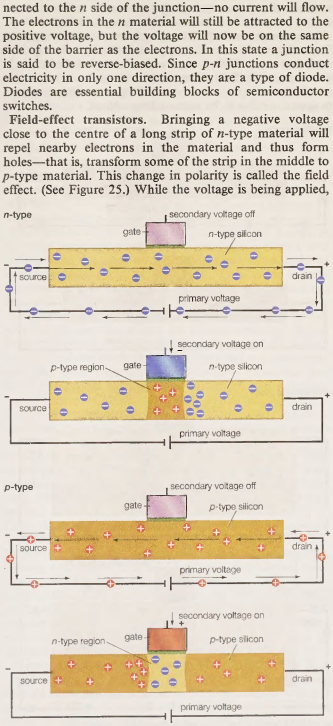

Figure 25: Basic field-effect transistor.

there will exist two *p-n* junctions along the strip, from *n* to *p* and then from *p* back to *n*. One of the two junctions will always be reverse-biased. Since reverse-biased junctions cannot conduct, current cannot flow through the strip.

The field effect can be used to create a switch (transistor) to turn current off and on, simply by applying and removing a small voltage nearby in order to create reverse-biased diodes in the material. A transistor created by using the field effect is called a field-effect transistor (FET). The location where the voltage is applied is known as a gate. The gate is separated from the transistor strip by a thin layer of insulation to prevent it from short-circuiting the flow of electrons through the semiconductor from an input (source) electrode to an output (drain) electrode.

Similarly, a switch can be made by placing a positive gate voltage near a strip of *p*-type material. A positive voltage attracts electrons and thus forms a region of *n* within a strip of *p*. This again creates two *p-n* junctions, or diodes. As before, one of the diodes will always be reverse-biased and will stop current from flowing.

FETs are good for building logic circuits because they require only a small current during switching. No current is required for holding the transistor in an on or off state; a voltage will maintain the state. This type of switching helps preserve battery life. A field-effect transistor is called unipolar (from "one polarity") because the main conduction method is either holes or electrons, not both.

Unipolar transistor

Enhancement mode FETs. There are two basic types of field-effect transistors. The type described previously is a depletion mode FET, since a region is depleted of its natural charge. The field effect can also be used to create what is called an enhancement mode FET by enhancing a region to appear similar to its surrounding regions.

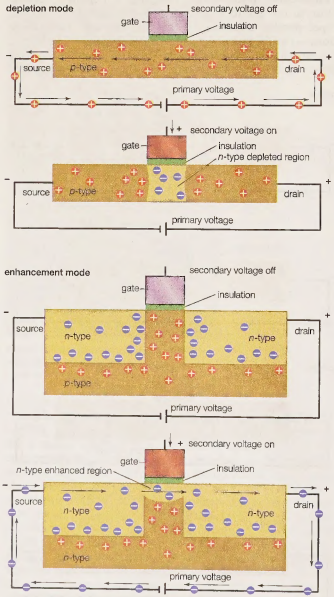

Figure 26: Depletion mode versus enhancement mode MOSFET.

An *n*-type enhancement mode FET is made from two regions of *n*-type material separated by a small region of *p*. As this FET naturally contains two *p-n* junctions—two diodes—it is normally switched off. However, when a positive voltage is placed on the gate, the voltage attracts electrons and creates *n*-type material in the middle region, filling the gap that was previously *p*-type material. The gate voltage thus creates a continuous region of *n* across the entire strip, allowing current to flow from one side to the other. This turns the transistor on. Similarly, a *p*-type enhancement mode FET can be made from two regions of *p*-type material separated by a small region of *n*. The gate voltage required for turning on this transistor is negative. Enhancement mode FETs switch faster than depletion mode FETs because they require a change only near the surface under the gate, rather than all the way through the material, as shown in Figure 26.

Complementary metal-oxide semiconductors. Recall that placing a positive voltage at the gate of an *n*-type enhanced mode FET will turn the switch on. Placing the same voltage at the gate of a *p*-type enhanced mode FET will turn the switch off. Likewise, placing a negative voltage at the gate will turn the *n*-type off and the *p*-type on. These FETs always respond in opposite, or complementary, fashion to a given gate voltage. Thus, if the gates of an *n*-type and a *p*-type FET are connected, as shown in Figure 21, any voltage applied to the common gate will operate the complementary pair, turning one on and leaving the other off.

A semiconductor that pairs *n*- and *p*-type transistors this way is called a complementary metal-oxide semiconductor (CMOS). Because complementary transistor pairs can quickly switch between two logic states, CMOSs are very useful in logic circuits. In particular, because only one circuit is on at any time, CMOSs require less power and are often used for battery-powered devices, such as in digital cameras, and for the special memory that holds the date, time, and system parameters in personal computers.

Bipolar transistors. Bipolar transistors simultaneously use holes and electrons to conduct, hence their name (from "two polarities"). Like FETs, bipolar transistors contain *p*- and *n*-type materials configured in input, middle, and output regions. In bipolar transistors, however, these regions are referred to as the emitter, the base, and the collector. Instead of relying, as FETs do, on a secondary voltage source to change the polarity beneath the gate (the field effect), bipolar transistors use a secondary voltage source to provide enough energy for electrons to punch through the reverse-biased base-collector junction (see Figure 27). As the electrons are energized, they jump into the collector and complete the circuit. Note that even with highly energetic electrons, the middle section of *p*-type material must be extremely thin for the electrons to pass through both junctions.

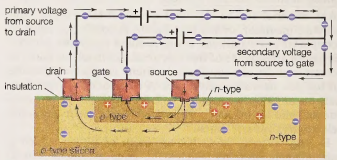

Figure 27: Bipolar transistor.

A bipolar base region can be fabricated that is much smaller than any CMOS transistor gate. This smaller size enables bipolar transistors to operate much faster than CMOS transistors. Bipolar transistors are typically used in applications where speed is very important, such as in radio-frequency ICs. On the other hand, although bipolar transistors are faster, FETs use less current. The type of switch a designer selects depends on which benefits are more important for the application: speed or power savings. This is one of many trade-off decisions engineers make in designing their circuits.

Speed versus current drain

DESIGNING ICS

All ICs use the same basic principles of voltage (V), current (I), and resistance (R). In particular, equations based on Ohm's law, $V = IR$, determine many circuit design choices. Design engineers must also be familiar with the properties of various electronic components needed for different applications.

Analog design. As mentioned earlier, an analog circuit takes an infinitely variable real-world voltage or current and modifies it in some useful way. The signal might be amplified, compared with another signal, mixed with other signals, separated from other signals, examined for value, or otherwise manipulated. For the design of this type of circuit, the choice of every individual component, size, placement, and connection is crucial. Unique decisions abound—for instance, whether one connection should be slightly wider than another connection, whether one resistor should be oriented parallel or perpendicular to another, or whether one wire can lie over the top of another. Every small detail affects the final performance of the end product.

When integrated circuits were much simpler, component values could be calculated by hand. For instance, a specific amplification value (gain) of an amplifier could typically be calculated from the ratio of two specific resistors. The current in the circuit could then be determined, using the resistor value required for the amplifier gain and the supply voltage used. As designs became more complex, laboratory measurements were used to characterize the devices. Engineers drew graphs of device characteristics across several variables and then referred to those graphs as they needed information for their calculations. As scientists improved their characterization of the intricate physics of each device, they developed complex equations that took into account subtle effects that were not apparent from coarse laboratory measurements. For example, a transistor works very differently at different frequencies, sizes, orientations, and placements. In particular, scientists found parasitic components (unwanted effects, usually resistance and capacitance) that are inherent in the way the devices are built. Parasitics become more problematic as the circuitry becomes more sophisticated and smaller and as it runs at higher frequencies.

Parasitic components

Although parasitic components in a circuit can now be accounted for by sophisticated equations, such calculations are very time-consuming to do by hand. For this work computers have become indispensable. In particular, a public-domain circuit-analysis program developed at the University of California, Berkeley, during the 1970s, SPICE (Simulation Program with Integrated Circuit Emphasis), and various proprietary models designed for use with it are ubiquitous in engineering courses and in industry for analog circuit design. SPICE has equations for transistors, capacitors, resistors, and other components, as well as for lengths of wires and for turns in wires, and it can reduce the calculation of circuit interactions to hours from the months formerly required for hand calculations.

Digital design. Since digital circuits involve millions of times as many components as analog circuits, much of the design work is done by copying and reusing the same circuit functions, especially by using digital design software that contains libraries of prestructured circuit components. The components available in such a library are of similar height, contain contact points in predefined locations, and have other rigid conformities so that they fit together regardless of how the computer configures a layout. While SPICE is perfectly adequate for analyzing analog circuits, with equations that describe individual components, the complexity of digital circuits requires a less-detailed approach. Therefore, digital analysis software ignores individual components for mathematical models of entire preconfigured circuit blocks (or logic functions).

Whether analog or digital circuitry is used depends on the function of a circuit. The design and layout of analog circuits are more demanding of teamwork, time, innovation, and experience, particularly as circuit frequencies get higher, though skilled digital designers and layout engineers can be of great benefit in overseeing an automated process as well. Digital design emphasizes different skills from analog design.

Mixed-signal design. For designs that contain both analog and digital circuitry (mixed-signal chips), standard analog and digital simulators are not sufficient. Instead, special behavioral simulators are used, employing the same simplifying idea behind digital simulators to model entire circuits rather than individual transistors. Behavioral simulators are designed primarily to speed up simulations of the analog side of a mixed-signal chip.

The difficulty with behavioral simulation is making sure that the model of the analog circuit function is accurate. Since each analog circuit is unique, it seems as though one must design the system twice—once to design the circuitry and once to design the model for the simulator.

FABRICATING ICS

The substrate material, or base wafer, on which ICs are built is a semiconductor, such as silicon or gallium arsenide. In order to obtain consistent performance, the semiconductor must be extremely pure and a single crystal.

Building layers. All sorts of devices, such as diodes, transistors, capacitors, and resistors, can be built with p- and n-type semiconductors. It is convenient to be able to manufacture all of these different electronic components from the same few basic manufacturing steps.

ICs are made of layers, from about 0.000005 to 0.1 millimetre thick, that are built on the semiconductor substrate one layer at a time, with perhaps 30 or more layers in a final chip. Creating the different electrical components on a chip is a matter of outlining exactly where areas of p- and n-type are to be located on each layer. Each layer is etched, using lines and geometric shapes in the exact locations where the material is to be deposited. Different colours represent different layers.

A wafer can be changed in one of three fundamental ways: by deposition (that is, adding a layer), by etching or removing a layer, or by implantation (altering a layer's composition). These processes are described below. (Further details on etching are described in the section *Photolithography*.)

Deposition. In a process known as film deposition, a thin film of some substance is deposited onto the wafer by means of either a chemical or a physical reaction.

Chemical methods. In one common method, known as chemical vapour deposition, the substrate is placed in a low-pressure chamber where certain gases are mixed and heated to 650–850 °C (1,200–1,550 °F) in order to form the desired solid film substance. The solid condenses from the mixed gases and "rains" evenly over the surface of a wafer. A special variant of this technique, known as epitaxy, slowly deposits silicon (or gallium arsenide) on the wafer to produce epitaxial growth of the crystal. Such films can be relatively thick (0.1 millimetre) and are commonly used for producing silicon-on-insulator substrates that lower the power requirements and speed the switching capabilities of CMOSs (described above in the section *Complementary metal-oxide semiconductors*). Another variation, known as plasma-enhanced (or plasma-assisted) chemical vapour deposition, uses low pressure and high voltage to create a plasma environment. The plasma causes the gases to react and precipitate at much lower temperatures of 300 to 350 °C (600 to 650 °F) and at faster rates, but this method tends to sacrifice uniformity of deposition.

Epitaxy

Two more chemical methods of deposition are electrodeposition (or electroplating) and thermal oxidation. In the former the substrate is given an electrically conducting coating and placed in a liquid solution (electrolyte) containing metal ions, such as gold, copper, or nickel. A wide range of film thicknesses can be built. In thermal oxidation the substrate is heated to 800–1,100 °C (1,500–2,000 °F), which causes the surface to oxidize. This process is often used to form a thin (0.0001-millimetre) insulating layer of silicon dioxide.

Physical methods. In general, physical methods of film deposition are less uniform than chemical methods; however, physical methods can be performed at lower temperatures and thus at less risk of damage to the substrate. A common physical method is sputtering. In sputtering, a wafer and a metal source are placed in a vacuum chamber,

Sputtering

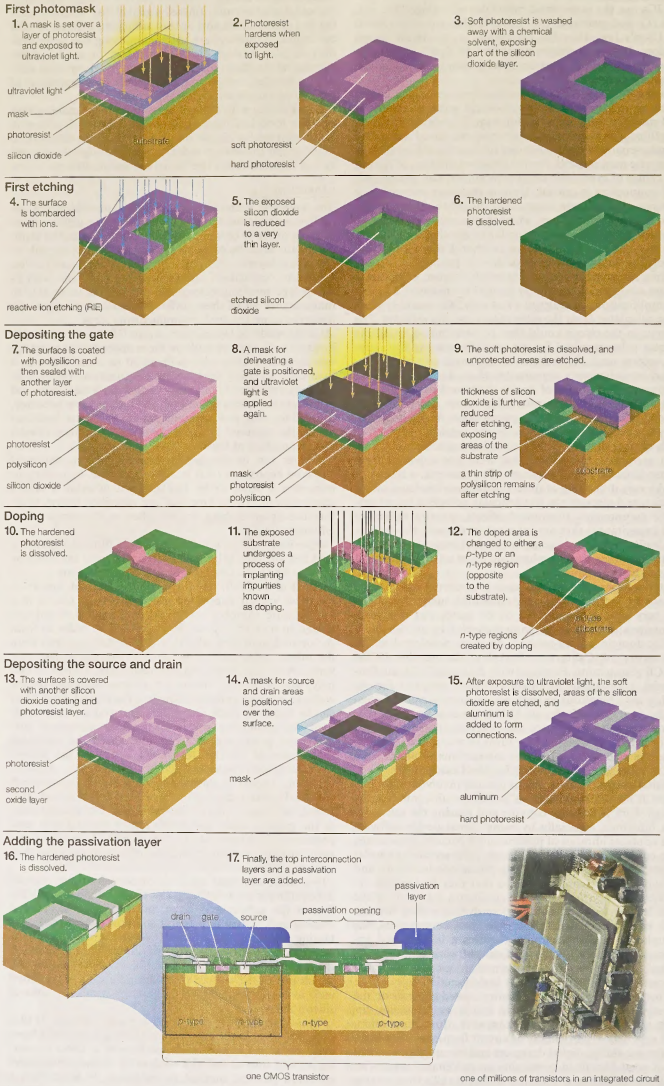

Figure 28: Integrated circuit fabrication.

and an inert gas such as argon is introduced at low pressure. The gas is then ionized by a radio-frequency power source, and the ions are accelerated by an electric field toward the metal surface. When these high-energy ions impact, they knock some of the metal atoms loose from the surface to form a vapour. This vapour condenses on the surfaces within the chamber, including the substrate, where it forms the desired film.

Evaporation deposition

In evaporation deposition, a metal source is heated in a vacuum chamber either by passing a current through a tungsten container or by focusing an electron beam on the metal's surface. As metal atoms evaporate, they form a vapour that condenses on the cooler surface of the wafer to form a layer.

Finally, in casting, a substance is dissolved in a solvent and sprayed on the wafer. After the solvent evaporates, an extremely thin film (perhaps a single layer of molecules) of the substance is left behind. Casting is typically used to add a photosensitive polymer coating, called the photoresist layer.

Etching. A layer can be removed, in entirety or in part, either by etching away the material with strong chemicals or by reactive ion etching (RIE). RIE is like sputtering in the argon chamber, but the polarity is reversed and different gas mixtures are used. The atoms on the surface of the wafer fly away, leaving it bare.

Implantation. Another method of modifying a wafer is to bombard its surface with extra atoms. This is called implantation. Enough of the atoms become deeply embedded in the surface to alter its characteristics, creating areas of *p*- and *n*-type materials. Overzealous atoms ripping through the nicely organized crystal lattice damage the structure of the wafer. After implantation the wafer is annealed (heated) to repair this damage. As a side effect of annealing, the implanted atoms usually move a little, diffusing into the surrounding material. The total area that contains implanted atoms after annealing is therefore called a diffusion layer.

Diffusion layer

A final passivation layer is added to the top of the wafer to seal it from water and other contaminants. Holes are etched through this layer in certain locations to make electrical contact with the integrated circuitry.

Photolithography. In order to alter specific locations on a wafer, a photoresist layer is first applied (as described above in the section *Deposition*). Photoresist, or just resist, typically dissolves in a high-pH solution after exposure to light (including ultraviolet radiation or X rays), and this process, known as development, is controlled by using a mask. A mask is made by applying a thick deposit of chromium in a particular pattern to a glass plate. The chromium provides a shadow over most of the wafer, allowing "light" to shine through only in desired locations, as shown in Figure 28. This enables the creation of extremely small areas—depending on the wavelength of the light used—that are unprotected by the hard resist.

After washing away the developed resist, the unprotected areas can be modified through the deposition, etching, or implantation processes described above, without affecting the rest of the wafer. Once such modifications are finished, the remaining resist is dissolved by a special solvent. This process is repeated with different masks at various layers (30 or so) to create changes to the wafer.

The person who designs the masks for each layer is called the layout engineer, or mask designer. The selection of circuit components and connections is given to mask designers by circuit designers, but mask designers have great latitude in deciding how the end product will be created, which layers will be used to build the components, how to design the connections, how it will look, how large it will be, and how well it will perform. Successful IC development is a team effort between circuit and mask designers.

The final package. After all the changes to the wafer have been completed, the thousands of individual IC units are sliced apart. This is called dicing the wafer. Each IC unit is now called a die. Dies resemble satellite images of cities, in which circuits look like roadways (see Figure 29). Each die that passes testing is placed into a hard plastic package. These plastic packages, called chips, are what one observes when looking at a computer's circuit board. The

Die

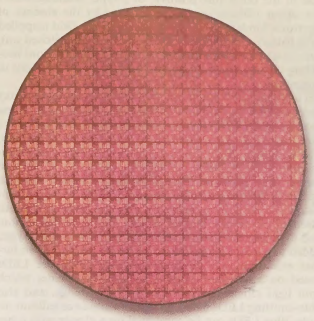

Figure 29: Using a 0.13-micron process, Intel can produce some 470 Pentium 4 chips from each 300-millimetre silicon wafer.

Copyright Intel Corporation

plastic packages have metal connection pins that connect the outside world (such as a computer board) to the proper contact points on the die through holes in the passivation layer. (Ch.St./Jy.L.St.)

Light-emitting diodes

A light-emitting diode (LED) is a semiconductor device that emits infrared or visible light when charged with an electric current. Visible LEDs are used in many electronic devices as indicator lamps, in automobiles as rear-window and brake lights, and on billboards and signs as alphanumeric displays or even full-colour posters. Infrared LEDs are employed in autofocus cameras and television remote controls and also as light sources in fibre-optic telecommunication systems.

The familiar lightbulb gives off light through incandescence, a phenomenon in which the heating of a wire filament by an electric current causes the wire to emit photons, the basic energy packets of light. LEDs operate by electroluminescence, a phenomenon in which the emission of photons is caused by electronic excitation of a material. The material used most often in LEDs is gallium arsenide, though there are many variations on this basic compound, such as aluminum gallium arsenide or aluminum gallium indium phosphide. These compounds are members of the so-called III-V group of semiconductors—that is, compounds made of elements listed in columns III and V of the periodic table. By varying the precise composition of the semiconductor, the wavelength (and therefore the colour) of the emitted light can be changed. LED emission is generally in the visible part of the spectrum (*i.e.*, with wavelengths from 0.4 to 0.7 micron) or in the near infrared (with wavelengths between 0.7 and 2.0 microns). The brightness of the light observed from an LED depends on the power emitted by the LED and on the relative sensitivity of the eye at the emitted wavelength. Maximum sensitivity occurs at 0.555 micron, which is in the yellow-orange and green region. The applied voltage in most LEDs is quite low, in the region of 2.0 volts; the current depends on the application and ranges from a few milliamperes to several hundred milliamperes.

Electroluminescence

The term diode refers to the twin-terminal structure of the light-emitting device. In a flashlight, for example, a wire filament is connected to a battery through two terminals, one (the anode) bearing the negative electric charge and the other (the cathode) bearing the positive charge. In LEDs, as in other semiconductor devices such as transistors, the "terminals" are actually two semiconductor materials of different composition and electronic properties brought together to form a junction. In one material (the negative, or *n*-type, semiconductor) the charge carriers are electrons,

and in the other (the positive, or *p*-type, semiconductor) the charge carriers are "holes" created by the absence of electrons. Under the influence of an electric field (supplied by a battery, for instance, when the LED is switched on), current can be made to flow across the *p*-*n* junction, providing the electronic excitation that causes the material to luminesce.

In a typical LED structure (see Figure 30) the clear epoxy dome serves as a structural element to hold the lead frame together, as a lens to focus the light, and as a refractive index match to permit more light to escape from the chip. The LED chip, typically 250 × 250 × 250 microns in dimension, is mounted in a reflecting cup formed in the lead frame. The *p*-*n*-type GaP:N layers represent nitrogen added to gallium phosphide to give green emission, the *p*-*n*-type GaAsP:N layers represent nitrogen added to gallium arsenide phosphide to give orange and yellow emission, and the *p*-type GaP:Zn,O layer represents zinc and oxygen added to gallium phosphide to give red emission. Two further enhancements, developed in the 1990s, are LEDs based on aluminum gallium indium phosphide, which emit light efficiently from green to red-orange, and also blue-emitting LEDs based on silicon carbide or gallium nitride. Blue LEDs can be combined on a cluster with other LEDs to give all colours, including white, for full-colour moving displays.

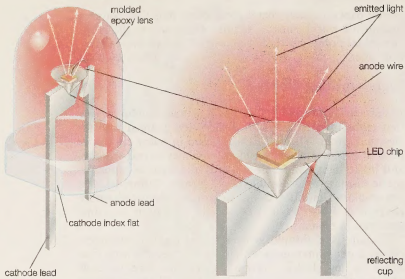

Figure 30: LED.

Any LED can be used as a light source for a short-range fibre-optic transmission system—that is, over a distance of less than 100 metres (330 feet). For long-range fibre optics, however, the emission properties of the light source are selected to match the transmission properties of the optical fibre, and in this case the infrared LEDs are a better match than the visible-light LEDs. Glass optical fibres suffer their lowest transmission losses in the infrared region at wavelengths of 1.3 and 1.55 microns. To match these transmission properties, LEDs are employed that are made of gallium indium arsenide phosphide layered on a substrate of indium phosphide. The exact composition of the material may be adjusted to emit energy precisely at 1.3 or 1.55 microns. (Ed.)

Infrared LEDs

Liquid crystal displays

A liquid crystal display (LCD) operates by applying a varying electric voltage to a layer of liquid crystal, thereby inducing changes in its optical properties. LCDs are commonly used for portable electronic games, as viewfinders for digital cameras and camcorders, in video projection systems, for electronic billboards, as monitors for computers, and in flat-panel televisions.

ELECTRO-OPTICAL EFFECTS IN LIQUID CRYSTALS

Liquid crystals are materials with a structure that is intermediate between that of liquids and crystalline solids. As in liquids, the molecules of a liquid crystal can flow past one another. As in solid crystals, however, they arrange themselves in recognizably ordered patterns. In common with solid crystals, liquid crystals can exhibit polymorphism; *i.e.*, they can take on different structural patterns, each with unique properties. LCDs utilize either nematic or smectic liquid crystals. The molecules of nematic liquid crystals align themselves with their axes in parallel, as shown in the figure. Smectic liquid crystals, on the other hand, arrange themselves in layered sheets; within different smectic phases, as shown in Figure 31, the molecules may take on different alignments relative to the plane of the sheets.

Polymorphism

The optical properties of liquid crystals depend on the direction light travels through a layer of the material. An electric field (induced by a small electric voltage) can change the orientation of molecules in a layer of liquid crystal and thus affect its optical properties. Such a process is termed an electro-optical effect, and it forms the basis for LCDs. For nematic LCDs, the change in optical properties results from orienting the molecular axes either along or perpendicular to the applied electric field, the preferred direction being determined by the details of the molecule's chemical structure. Liquid crystal materials that align either parallel or perpendicular to an applied field can be selected to suit particular applications. The small electric voltages necessary to orient liquid crystal molecules have been a key feature of the commercial success of LCDs; other display technologies have rarely matched their low power consumption.

TWISTED NEMATIC DISPLAYS

The first LCDs became commercially available in the late 1960s and were based on a light-scattering effect known as the dynamic scattering mode. These displays were used in many watches and pocket calculators because of their low power consumption and portability. However, problems connected with their readability and the limited lifetime of their liquid crystal materials led to the development during the 1970s of twisted nematic (TN) displays, variants of which are now available in computer monitors and flat-panel televisions.

Dynamic scattering mode

A TN cell consists of upper and lower substrate plates separated by a narrow gap (typically 5–10 microns) filled with a layer of liquid crystal. The substrate plates are normally transparent glass and carry patterned electrically conducting transparent coatings of indium tin oxide. The electrode layers are coated with a thin aligning layer of a polymer that causes the liquid crystal molecules in contact with

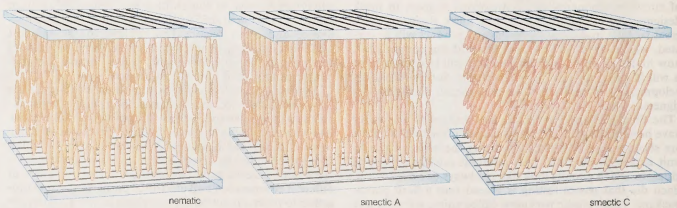

Figure 31: Nematic, smectic A, and smectic C liquid crystals.

them to align approximately parallel to the surface. In most currently manufactured displays, the alignment layers consist of a layer of polymer a few tens of nanometres thick (1 nanometre = 10^{-9} metre) that has been rubbed with a cloth in only one direction. In assembling the cell, the top and bottom substrate plates are arranged so that the alignment directions are perpendicular to each other. The whole assembly is then contained between a pair of sheet polarizers, which also have their light-absorption axes perpendicular to each other. In the absence of any voltage, the perpendicular alignment layers cause the liquid crystal to adopt a twisted configuration from one plate to the other. With no liquid crystal present, light passing in either direction through the cell would be absorbed because of the crossed polarizers, and the cell would appear to be dark. In the presence of a liquid crystal layer, however, the cell appears to be transparent because the optics of the twisted liquid crystal match the crossed arrangement of the polarizers. Application of three to five volts across the liquid crystal destroys the twisted state and causes the molecules to orient perpendicular to the substrate plates, giving a dark appearance to the cell, as shown in the diagram. For simple displays, the liquid crystal cell is operated in a reflective mode, with a diffuse reflector placed behind the display, and the activated parts of the electrode pattern appear as black images on a gray background provided by the diffuse reflector. By patterning the electrodes in segments or as an array of small squares, it is possible to display alphanumeric characters and very low-resolution images—for example, in digital watches or calculators.

More-complex images can be displayed using a technique known as passive-matrix addressing (described below). However, even with this technique, 90° TN displays can produce images consisting of only about 20 rows of picture elements, known as pixels.

SUPERTWISTED NEMATIC DISPLAYS

It was discovered in the early 1980s that increasing the twist angle of a liquid crystal cell to about 180–270° (with 240° being fairly common) allows a much larger number of pixel rows to be used, with a consequent increase in the complexity of images that can be displayed. These supertwisted nematic (STN) displays achieve their high twist by using a substrate plate configuration similar to that of TN displays but with an additional optically active compound, known as a chiral dopant, dissolved in the liquid crystal. The display is activated using passive-matrix addressing, for which the pixels are arranged in rows and columns; selective application of a voltage to a particular row and column will activate the corresponding element at their intersection. The supertwist causes a larger relative change in optical transmission with applied voltage, compared with 90° twisted cells. This reduces the illumination of unwanted pixels, so-called "cross talk," which controls the number of rows that can be activated in passive-matrix addressing. Colour STN displays have been produced for computer monitors, but they are being replaced in the market by more modern thin-film transistor TN displays (described below), which have better viewing angles, colour, and response speed. Monochrome STN displays are still widely used in mobile telephones and other devices that do not require colour.

Chiral dopant

THIN-FILM TRANSISTOR DISPLAYS

The display of complex images requires high-resolution dot-matrix displays consisting of many thousands of pixels. For example, the video graphics array (VGA) standard for computer monitors consists of an array of 640 by 480 picture elements, which for a colour LCD translates to 921,600 individual pixels. Excellent images can be built up from arrays of this complexity by using thin-film transistor (TFT) TN displays, in which each pixel has associated with it a silicon transistor that acts as an individual electronic switch. (A cutaway portion of a TFT display is illustrated in Figure 32.) The use of a transistor for each pixel makes the TFT an active-matrix display, as opposed to the passive-matrix display described in the previous section. The TN effect produces black-and-white images, but, as shown in the diagram, colour images can be generated by forming

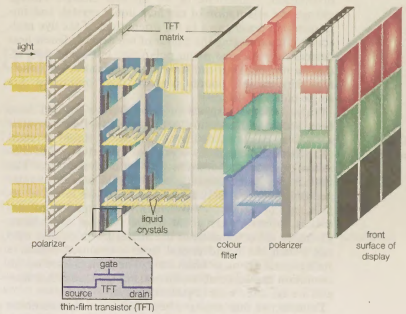

Figure 32: Basic architecture of an active-matrix thin-film transistor LCD.

three-pixel groups using red, blue, and green filters. The displayed image is bright by virtue of a flat backlight placed behind the liquid crystal panel.

Introduced at the end of the 1980s, TFT displays are now widely used in portable computers and as space-saving flat-screen monitors for personal computers. Some aspects of TFTs, such as viewing angle, speed, and the manufacturing cost of large-area displays, have slowed their full commercial exploitation. Nevertheless, these LCDs are increasingly entering the home television market.

OTHER TRANSMISSIVE NEMATIC DISPLAYS

In recent years a number of alternatives to the 90° TN have been commercialized for use on active-matrix substrates. For example, in-plane switching (IPS) displays operate by applying a switching voltage to electrodes on a single substrate to untwist the liquid crystal. IPS displays have a viewing angle intrinsically superior to that of TFT TNs; however, the requirement for more electrode circuitry on their substrate can result in a less efficient use of the backlight. Twisted vertically aligned nematic (TVAN) displays utilize molecules that tend to orient with their long axes perpendicular to the direction of an applied electric field. A small quantity of an optically active material is added to the liquid crystal, causing it to adopt a twisted configuration upon the application of voltage. TVAN displays can show very high contrast and good viewing-angle characteristics.

TVAN

REFLECTIVE DISPLAYS

The backlight of LCDs typically accounts for more than 80 percent of the display's power consumption. For mobile complex displays, battery lifetime is of great importance, and clearly the development of products that can be viewed in ambient light without recourse to backlighting is highly desirable. Such displays are known as reflective displays, and they can be realized in a number of ways. Some commercial reflective displays operate much like the transmissive STN. The liquid crystal again acts as an electro-optical layer between two polarizers. In place of a backlight, however, an aluminum mirror is used to reflect ambient light back toward the viewer when the liquid crystal is switched to a bright (or transmissive) state. Polarizers absorb about 50 percent of unpolarized light passing through them, and the removal of one or both polarizers can increase the brightness of the reflective displays. Indeed, active-matrix devices with single polarizers have begun to dominate the high-quality reflective display market—for example, in mobile phones and handheld electronic games.

Another type of reflective device, known as a guest-host reflective display, relies on dissolving "guest" dye molecules into a "host" liquid crystal. The dye molecules are selected to have a colour absorption that depends on their

orientation. Variations in an applied electric voltage change the orientation of the host liquid crystal, and this in turn induces changes in the orientation of the dye molecules, thus changing the colour of the display. Guest-host devices may use one or no polarizers, but again they require a mirror. They can show high brightness, but generally they exhibit poorer contrast than optimized TN single-polarizer devices.

Truly reflective displays (not requiring a mirror) have been manufactured using optically active liquid crystals known as chiral nematics or cholesteric liquid crystals. (The first chiral nematics were based on derivatives of cholesterol, hence the now-obsolete term cholesteric.) The molecules of such optically active liquid crystals spontaneously order into helical structures that are found to reflect light of a specific wavelength (*i.e.*, a specific colour) that is approximately equal to the pitch of the helices. Changing the orientation of the helices by an electric field can switch the liquid crystal from a coloured reflective state to a scattering or black state. The devices have a high resolution and acceptable contrast, but they are rather slow and are typically used in static displays.

Chiral nematics

Transflective displays have been developed that combine some of the features of polarizer-based reflective displays and transmissive displays. Transflective devices use a mirror that is partially reflective and partially transmissive, situated between the liquid crystal layer and a backlight. When ambient light levels are high, the backlight may be turned off and the display operated as a reflective device, saving battery power. When light levels are low, the backlight may be turned on to increase the brightness of the display. This clearly has advantages, although transflective displays by their nature represent a compromise and cannot readily match the reflectivity of a dedicated reflective display or the brightness of a transmissive device.

PROJECTION DISPLAYS

The LCDs used in projection systems are typically small reflective or transmissive panels illuminated by a powerful arc lamp source. A series of lenses magnifies the reflected or transmitted image and casts it onto a screen. In front-projection systems the LCD is situated on the same side of the screen as the viewer, while in rear-projection systems the screen is illuminated from behind. Projectors of higher cost and performance may use three separate LCD panels, forming separate red, green, and blue images that combine to form a coloured image on the screen.

SMECTIC LCDS

The increasing demand for video displays has placed a growing emphasis on the switching speed of liquid crystals. This has led to the development of devices employing smectic liquid crystals, certain of which have a faster electro-optical response than nematic liquid crystals. The surface-stabilized ferroelectric liquid crystal (SSFLC) display is currently the most developed smectic device. In it the liquid crystal molecules are arranged in layers perpendicular to the substrate planes, which are separated by one or two microns, and within the layers the molecules are tilted, as illustrated in Figure 31. The host liquid crystal contains optically active molecules, and a subtle consequence of the optical activity and the tilt of the molecules is the appearance of a permanent charge separation, or ferroelectric dipole, analogous to the ferromagnetic dipole of a magnet. The direction of this dipole is perpendicular to the tilt direction of the molecules and in the plane of the layers. Thus, there is a permanent charge separation across the liquid crystal layer in the SSFLC, and its sign is directly coupled to the tilt direction of the molecules. An applied voltage of the correct sign can reverse the direction of this dipole in tens of microseconds and hence reverse the tilt direction of the molecules. The corresponding change in optical properties can cause a change from light to dark when one or more polarizers are used.

SSFLC

SSFLC devices have been commercialized for large passive-matrix displays, but their cost and complexity have prevented them from making any significant impact on the market. Small transmissive and reflective active-matrix SSFLC displays, however, show some promise for use as elements in projection systems or as viewfinders in digital cameras. Their fast response allows them to be used in time-sequential colour systems, in which costly colour filters are replaced by a coloured backlight that flashes red, green, and blue in rapid succession (about 100 cycles per second). For example, the liquid crystal can be switched to a transmissive state during the red and green periods and to a nontransmissive state during the blue period, with the result that the eye sees an average of red and green light, or the colour yellow. (D.A.Dr./H.G.W.)

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Elizabeth I of England

Elizabeth I was queen of England from 1558 to 1603. Though her small kingdom was threatened by grave internal divisions, Elizabeth's blend of shrewdness, courage, and majestic self-display inspired ardent expressions of loyalty and helped unify the nation against foreign enemies. The adulation bestowed upon her both in her lifetime and in the ensuing centuries was not altogether a spontaneous effusion; it was the result of a carefully crafted, brilliantly executed campaign in which the queen fashioned herself as the glittering symbol of the nation's destiny. This political symbolism, common to monarchies, had more substance than usual, for the queen was by no means a mere figurehead. While she did not wield the absolute power of which Renaissance rulers dreamed, she tenaciously upheld her authority to make critical decisions and to set the central policies of both state and church. The latter half of the 16th century in England is justly called the Elizabethan era: rarely has the collective life of a whole age been given so distinctively personal a stamp.

From the Woburn Abbey Collection, by kind permission of His Grace, the Duke of Bedford



Elizabeth I, the Armada portrait by Gower (d. 1596). In Woburn Abbey, Bedfordshire.

Childhood. Elizabeth's early years were not auspicious. She was born at Greenwich Palace on Sept. 7, 1533, the daughter of the Tudor king Henry VIII and his second wife, Anne Boleyn. Henry had defied the pope and broken England from the authority of the Roman Catholic church in order to dissolve his marriage with his first wife, Catherine of Aragon, who had borne him a daughter, Mary. Since the king ardently hoped that Anne Boleyn would give birth to the male heir regarded as the key to stable dynastic succession, the birth of a second daughter was a bitter disappointment that dangerously weakened the new queen's position. Before Elizabeth reached her third birthday, her father had her mother beheaded on charges of adultery and treason. Moreover, at Henry's instigation, an act of Parliament declared his marriage with Anne Boleyn invalid from the beginning, thus making their daughter Elizabeth illegitimate, as Roman Catholics had all along claimed her to be. (Apparently the king was undeterred by the logical inconsistency of simultaneously invalidating the marriage and accusing his wife of adultery.) The emotional impact of these events on the little girl, who had been brought up from infancy in a separate household at Hatfield, is not known; presumably no one thought it worth recording. What was noted was her precocious seriousness; at six years old, it was admiringly observed, she had as much gravity as if she had been 40.

Loss of mother

When in 1537 Henry's third wife, Jane Seymour, gave birth to a son, Edward, Elizabeth receded still further into relative obscurity, but she was not neglected. Despite his capacity for monstrous cruelty, Henry VIII treated all his children with what contemporaries regarded as affection; Elizabeth was present at ceremonial occasions and was declared third in line to the throne. She spent much of the time with her half brother Edward and, from her 10th year onward, profited from the loving attention of her stepmother, Catherine Parr, the king's sixth and last wife. Under a series of distinguished tutors, of whom the best known is the Cambridge humanist Roger Ascham, Elizabeth received the rigorous education normally reserved for male heirs, consisting of a course of studies centring on classical languages, history, rhetoric, and moral philosophy. "Her mind has no womanly weakness," Ascham wrote with the unselfconscious sexism of the age, "her perseverance is equal to that of a man, and her memory long keeps what it quickly picks up." In addition to Greek and Latin, she became fluent in French and Italian, attainments of which she was proud and which were in later years to serve her well in the conduct of diplomacy. Thus steeped in the secular learning of the Renaissance, the quick-witted and intellectually serious princess also studied theology, imbibing the tenets of English Protestantism in its formative period. Her association with the Reformation is critically important, for it shaped the future course of the nation, but it does not appear to have been a personal passion: observers noted the young princess's fascination more with languages than with religious dogma.

Education

Position under Edward VI and Mary. With her father's death in 1547 and the accession to the throne of her frail 10-year-old brother Edward, Elizabeth's life took a perilous turn. Her guardian, the dowager queen Catherine Parr, almost immediately married Thomas Seymour, the lord high admiral. Handsome, ambitious, and discontented, Seymour began to scheme against his powerful older brother, Edward Seymour, protector of the realm during Edward VI's minority. In January 1549, shortly after the death of Catherine Parr, Thomas Seymour was arrested for treason and accused of plotting to marry Elizabeth in order to rule the kingdom. Repeated interrogations of Elizabeth and her servants led to the charge that even when his wife was alive Seymour had on several occasions behaved in a flirtatious and overly familiar manner toward the young princess. Under humiliating close questioning and in some danger, Elizabeth was extraordinarily circumspect and poised. When she was told that Seymour had been beheaded, she betrayed no emotion.

The need for circumspection, self-control, and political acumen became even greater after the death of the Protestant Edward in 1553 and the accession of Elizabeth's older half sister Mary, a religious zealot set on returning England, by force if necessary, to the Roman Catholic faith. This attempt, along with her unpopular marriage to the ardently Catholic king Philip II of Spain, aroused bitter Protestant opposition. In a charged atmosphere of treasonous rebellion and inquisitorial repression, Elizabeth's life was in grave danger. For though, as her sister demanded, she conformed outwardly to official Catholic observance, she inevitably became the focus and the obvious beneficiary of plots to overthrow the government and restore Protestantism. Arrested and sent to the Tower of London after Sir Thomas Wyatt's rebellion in January 1554, Elizabeth narrowly escaped her mother's fate. Two months later, after extensive interrogation and spying had revealed no conclusive evidence of treason on her part, she was released from the Tower and placed in close custody for a year at Woodstock. The difficulty of her situation eased somewhat, though she was never far from suspicious scrutiny. Throughout the unhappy years of Mary's childless reign, with its burning of Protestants and its military disasters, Elizabeth had continually to protest her innocence, affirm her unwavering loyalty, and proclaim

Sent to the Tower

her pious abhorrence of heresy. It was a sustained lesson in survival through self-discipline and the tactful manipulation of appearances.

Many Protestants and Roman Catholics alike assumed that her self-presentation was deceptive, but Elizabeth managed to keep her inward convictions to herself, and in religion as in much else they have remained something of a mystery. There is with Elizabeth a continual gap between a dazzling surface and an interior that she kept carefully concealed. Observers were repeatedly tantalized with what they thought was a glimpse of the interior, only to find that they had been shown another facet of the surface. Everything in Elizabeth's early life taught her to pay careful attention to how she represented herself and how she was represented by others. She learned her lesson well.

Accession. At the death of Mary on Nov. 17, 1558, Elizabeth came to the throne amid bells, bonfires, patriotic demonstrations, and other signs of public jubilation. Her entry into London and the great coronation procession that followed were masterpieces of political courtship. "If ever any person," wrote one enthusiastic observer, "had either the gift or the style to win the hearts of people, it was this Queen, and if ever she did express the same it was at that present, in coupling mildness with majesty as she did, and in stately stooping to the meanest sort." Elizabeth's smallest gestures were scrutinized for signs of the policies and tone of the new regime: When an old man in the crowd turned his back on the new queen and wept, Elizabeth exclaimed confidently that he did so out of gladness; when a girl in an allegorical pageant presented her with a Bible in English translation—banned under Mary's reign—Elizabeth kissed the book, held it up reverently, and then laid it on her breast; and when the abbot and monks of Westminster Abbey came to greet her in broad daylight with candles in their hands, she briskly dismissed them with the words "Away with those torches! we can see well enough." Spectators were thus assured that under Elizabeth England had returned, cautiously but decisively, to the Reformation.

The first weeks of her reign were not entirely given over to symbolic gestures and public ceremonial. The queen began at once to form her government and issue proclamations. She reduced the size of the Privy Council, in part to purge some of its Catholic members and in part to make it more efficient as an advisory body; she began a restructuring of the enormous royal household; she carefully balanced the need for substantial administrative and judicial continuity with the desire for change; and she assembled a core of experienced and trustworthy advisers, including William Cecil, Nicholas Bacon, Francis Walsingham, and Nicholas Throckmorton. Chief among these was Cecil (afterward Lord Burghley), whom Elizabeth appointed her principal secretary of state on the morning of her accession and who was to serve her (first in this capacity and after 1571 as lord treasurer) with remarkable sagacity and skill for 40 years.

The woman ruler in a patriarchal world. In the last year of Mary's reign, the Scottish Calvinist preacher John Knox wrote in his *The First Blast of the Trumpet Against the Monstruous Regiment of Women* that "God hath revealed to some in this our age that it is more than a monster in nature that a woman should reign and bear empire above man." With the accession of the Protestant Elizabeth, Knox's trumpet was quickly muted, but there remained a widespread conviction, reinforced by both custom and teaching, that, while men were naturally endowed with authority, women were temperamentally, intellectually, and morally unfit to govern. Men saw themselves as rational beings; they saw women as creatures likely to be dominated by impulse and passion. Gentlemen were trained in eloquence and the arts of war; gentlewomen were urged to keep silent and attend to their needlework. In men of the upper classes a will to dominate was admired or at least assumed; in women it was viewed as dangerous or grotesque.

A woman on the throne

Apologists for the queen countered that there had always been significant exceptions, such as the biblical Deborah, the prophetess who had judged Israel. Crown lawyers, moreover, elaborated a mystical legal theory known as "the king's two bodies." When she ascended the throne, according to this theory, the queen's whole being was profoundly altered: her mortal "body natural" was wedded to an immortal "body politic." "I am but one body, naturally considered," Elizabeth declared in her accession speech, "though by [God's] permission a Body Politic to govern." Her body of flesh was subject to the imperfections of all human beings (including those specific to womankind), but the body politic was timeless and perfect. Hence in theory the queen's gender was no threat to the stability and glory of the nation.

Elizabeth made it immediately clear that she intended to rule in more than name only and that she would not subordinate her judgment to that of any one individual or faction. Since her sister's reign did not provide a satisfactory model for female authority, Elizabeth had to improvise a new model, one that would overcome the considerable cultural liability of her sex. Moreover, quite apart from this liability, any English ruler's power to compel obedience had its limits. The monarch was at the pinnacle of the state, but that state was relatively impoverished and weak, without a standing army, an efficient police force, or a highly developed, effective bureaucracy. To obtain sufficient revenue to govern, the crown had to request subsidies and taxes from a potentially fractious and recalcitrant Parliament. Under these difficult circumstances, Elizabeth developed a strategy of rule that blended imperious command with an extravagant, histrionic cult of love.

The Virgin Queen

The cult of Elizabeth as the Virgin Queen wedded to her kingdom was a gradual creation that unfolded over many years, but its roots may be glimpsed at least as early as 1555. At that time, according to a report that reached the French court, Queen Mary had proposed to marry her sister to the staunchly Catholic duke of Savoy; the usually cautious and impassive Elizabeth burst into tears, declaring that she had no wish for any husband. Other matches were proposed and summarily rejected. But in this vulnerable period of her life there were obvious reasons for Elizabeth to bide her time and keep her options open. No one—not even the princess herself—need have taken very seriously her professed desire to remain single. When she became queen, speculation about a suitable match immediately intensified, and the available options became a matter of grave national concern. Beyond the general conviction that the proper role for a woman was that of a wife, the dynastic and diplomatic stakes in the projected royal marriage were extremely high. If Elizabeth died childless, the Tudor line would come to an end. The nearest heir was Mary, Queen of Scots, the granddaughter of Henry VIII's sister Margaret. Mary, a Catholic whose claim was supported by France and other powerful Catholic states, was regarded by Protestants as a nightmarish threat that could best be averted if Elizabeth produced a Protestant heir.

The queen's marriage was critical not only for the question of succession but also for the tangled web of international diplomacy. England, isolated and militarily weak, was sorely in need of the major alliances that an advantageous marriage could forge. Important suitors eagerly came forward: Philip II of Spain, who hoped to renew the link between Catholic Spain and England; Archduke Charles of Austria; Erik XIV, king of Sweden; Henry, Duke d'Anjou and later king of France; François, Duke d' Alençon; and others. Many scholars think it unlikely that Elizabeth ever seriously intended to marry any of these aspirants to her hand, for the dangers always outweighed the possible benefits, but she skillfully played one off against another and kept the marriage negotiations going for months, even years, at one moment seeming on the brink of acceptance, at the next veering away toward vows of perpetual virginity. "She is a Princess," the French ambassador remarked, "who can act any part she pleases."

English suitors

Elizabeth was courted by English suitors as well, most assiduously by her principal favourite, Robert Dudley, Earl of Leicester. As master of the horse and a member of the Privy Council, Leicester was constantly in attendance on the queen, who displayed toward him all the signs of an ardent romantic attachment. When in September 1560 Leicester's wife, Amy Robsart, died in a suspicious fall, the favourite seemed poised to marry his royal mis-

tress—so at least widespread rumours had it—but, though the queen's behaviour toward him continued to generate scandalous gossip, the decisive step was never taken. Elizabeth's resistance to a marriage she herself seemed to desire may have been politically motivated, for Leicester had many enemies at court and an unsavory reputation in the country at large. But in October 1562 the queen nearly died of smallpox, and, faced with the real possibility of a contested succession and a civil war, even rival factions were likely to have countenanced the marriage.

Probably at the core of Elizabeth's decision to remain single was an unwillingness to compromise her power. Sir Robert Naunton recorded that the queen once said angrily to Leicester, when he tried to insist upon a favour, "I will have here but one mistress and no master." To her ministers she was steadfastly loyal, encouraging their frank counsel and weighing their advice, but she did not cede ultimate authority even to the most trusted. Though she patiently received petitions and listened to anxious advice, she zealously retained her power to make the final decision in all crucial affairs of state. Unsolicited advice could at times be dangerous: when in 1579 a pamphlet was published vehemently denouncing the queen's proposed marriage to the Catholic Duke d'Alençon, its author John Stubbs and his publisher William Page were arrested and had their right hands chopped off.

Elizabeth's performances—her displays of infatuation, her apparent inclination to marry the suitor of the moment—often convinced even close advisers, so that the level of intrigue and anxiety, always high in royal courts, often rose to a feverish pitch. Far from trying to allay the anxiety, the queen seemed to augment and use it, for she was skilled at manipulating factions. This skill extended beyond marriage negotiations and became one of the hallmarks of her regime. A powerful nobleman would be led to believe that he possessed unique influence over the queen, only to discover that a hated rival had been led to a comparable belief. A golden shower of royal favour—apparent intimacies, public honours, the bestowal of such valuable perquisites as land grants and monopolies—would give way to royal aloofness or, still worse, to royal anger. The queen's anger was particularly aroused by challenges to what she regarded as her prerogative (whose scope she cannily left undefined) and indeed by any unwelcome signs of independence. The courtly atmosphere of vivacity, wit, and romance would then suddenly chill, and the queen's behaviour, as her godson Sir John Harington put it, "left no doubtings whose daughter she was." This identification of Elizabeth with her father, and particularly with his capacity for wrath, is something that the queen herself—who never made mention of her mother—periodically invoked.

A similar blend of charm and imperiousness characterized the queen's relations with Parliament, on which she had to depend for revenue. Many sessions of Parliament, particularly in the early years of her rule, were more than cooperative with the queen; they had the rhetorical air of celebrations. But under the strain of the marriage-and-succession question, the celebratory tone, which masked serious policy differences, began over the years to wear thin, and the sessions involved complicated, often acrimonious negotiations between crown and commons. More radical members of Parliament wanted to include in debate broad areas of public policy; the queen's spokesmen struggled to restrict free discussion to government bills. Elizabeth had a rare gift for combining calculated displays of intransigence with equally calculated displays of graciousness and, on rare occasions, a prudent willingness to concede. Whenever possible, she transformed the language of politics into the language of love, likening herself to the spouse or the mother of her kingdom. Characteristic of this rhetorical strategy was her famous "Golden Speech" of 1601, when, in the face of bitter parliamentary opposition to royal monopolies, she promised reforms:

> I do assure you, there is no prince that loveth his subjects better, or whose love can countervail our love. There is no jewel, be it of never so rich a price, which I set before this jewel; I mean, your love: for I do more esteem of it, than of any treasure or riches.

Relations with Parliament

A discourse of rights or interests thus became a discourse of mutual gratitude, obligation, and love. "We all loved her," Harington wrote with just a trace of irony, "for she said she loved us." In her dealings with parliamentary delegations, as with suitors and courtiers, the queen contrived to turn her gender from a serious liability into a distinct advantage.

Religious questions and the fate of Mary, Queen of Scots. Elizabeth restored England to Protestantism. The Act of Supremacy, passed by Parliament and approved in 1559, revived the antipapal statutes of Henry VIII and declared the queen supreme governor of the church, while the Act of Uniformity established a slightly revised version of the second Edwardian prayer book as the official order of worship. Elizabeth's government moved cautiously but steadily to transfer these structural and liturgical reforms from the statute books to the local parishes throughout the kingdom. Priests, temporal officers, and men proceeding to university degrees were required to swear an oath to the royal supremacy or lose their positions; absence from Sunday church service was punishable by a fine; royal commissioners sought to ensure doctrinal and liturgical conformity. Many of the nobles and gentry, along with a majority of the common people, remained loyal to the old faith, but all the key positions in the government and church were held by Protestants who employed patronage, pressure, and propaganda, as well as threats, to secure an outward observance of the religious settlement.

Militant Protestants

But to militant Protestants, including exiles from the reign of Queen Mary newly returned to England from Calvinist Geneva and other centres of continental reform, these measures seemed hopelessly pusillanimous and inadequate. They pressed for a drastic reform of the church hierarchy and church courts, a purging of residual Catholic elements in the prayer book and ritual, and a vigorous searching out and persecution of recusants. Each of these demands was repugnant to the queen. She felt that the reforms had gone far enough and that any further agitation would provoke public disorder, a dangerous itch for novelty, and an erosion of loyalty to established authority. Elizabeth, moreover, had no interest in probing the inward convictions of her subjects; provided that she could obtain public uniformity and obedience, she was willing to let the private beliefs of the heart remain hidden. This policy was consistent with her own survival strategy, her deep conservatism, and her personal dislike of evangelical fervour. When in 1576 the archbishop of Canterbury, Edmund Grindal, refused the queen's orders to suppress certain reformist educational exercises, called "propheseyings," Grindal was suspended from his functions and never restored to them. Upon Grindal's death, Elizabeth appointed a successor, Archbishop Whitgift, who vigorously pursued her policy of an authoritarian ecclesiastical regime and a relentless hostility to Puritan reformers.

The Catholic opposition

If Elizabeth's religious settlement was threatened by Protestant dissidents, it was equally threatened by the recalcitrance and opposition of English Catholics. At first this opposition seemed relatively passive, but a series of crises in the late 1560s and early '70s disclosed its potential for serious, even fatal, menace. In 1569 a rebellion of feudal aristocrats and their followers in the staunchly Catholic north of England was put down by savage military force; while in 1571 the queen's informers and spies uncovered an international conspiracy against her life, known as the Ridolfi Plot. Both threats were linked at least indirectly to Mary, Queen of Scots, who had been driven from her own kingdom in 1568 and had taken refuge in England. The presence, more prisoner than guest, of the woman whom the Roman Catholic church regarded as the rightful queen of England posed a serious political and diplomatic problem for Elizabeth, a problem greatly exacerbated by Mary's restless ambition and penchant for conspiracy. Elizabeth judged that it was too dangerous to let Mary leave the country, but at the same time she firmly rejected the advice of Parliament and many of her councillors that Mary should be executed. So a captive, at once ominous, malevolent, and pathetic, Mary remained.

The alarming increase in religious tension, political intrigue, and violence was not only an internal, English

concern. In 1570 Pope Pius V excommunicated Elizabeth and absolved her subjects from any oath of allegiance that they might have taken to her. The immediate effect was to make life more difficult for English Catholics, who were the objects of a suspicion that greatly intensified in 1572 after word reached England of the St. Bartholomew's Day massacre of Protestants (Huguenots) in France. Tension and official persecution of recusants increased in the wake of the daring clandestine missionary activities of English Jesuits, trained on the Continent and smuggled back to England. Elizabeth was under great pressure to become more involved in the continental struggle between Roman Catholics and Protestants, in particular to aid the rebels fighting the Spanish armies in the Netherlands. But she was very reluctant to become involved, in part because she detested rebellion, even rebellion undertaken in the name of Protestantism, and in part because she detested expenditures. Eventually, after vacillations that drove her councillors to despair, she agreed first to provide some limited funds and then, in 1585, to send a small expeditionary force to the Netherlands.

Fears of an assassination attempt against Elizabeth increased after Pope Gregory XIII proclaimed in 1580 that it would be no sin to rid the world of such a miserable heretic. In 1584 Europe's other major Protestant leader, William of Orange, was assassinated. Elizabeth herself showed few signs of concern—throughout her life she was a person of remarkable personal courage—but the anxiety of the ruling elite was intense. In an ugly atmosphere of intrigue, torture and execution of Jesuits, and rumours of foreign plots to kill the queen and invade England, Elizabeth's Privy Council drew up a Bond of Association, pledging its signers, in the event of an attempt on Elizabeth's life, to kill not only the assassins but also the claimant to the throne in whose interest the attempt had been made. The Association was clearly aimed at Mary, whom government spies, under the direction of Sir Francis Walsingham, had by this time discovered to be thoroughly implicated in plots against the queen's life. When Walsingham's men in 1586 uncovered the Babington Plot, another conspiracy to murder Elizabeth, the wretched Queen of Scots, her secret correspondence intercepted and her involvement clearly proved, was doomed. Mary was tried and sentenced to death. Parliament petitioned that the sentence be carried out without delay. For three months the queen hesitated and then with every sign of extreme reluctance signed the death warrant. When the news was brought to her that on Feb. 8, 1587, Mary had been beheaded, Elizabeth responded with an impressive show of grief and rage. She had not, she wrote to Mary's son, James VI of Scotland, ever intended that the execution actually take place, and she imprisoned the man who had delivered the signed warrant. It is impossible to know how many people believed Elizabeth's professions of grief; Catholics on the Continent wrote bitter denunciations of the queen, while Protestants throughout the kingdom enthusiastically celebrated the death of a woman they had feared and hated.

The Babington Plot

For years Elizabeth had cannily played a complex diplomatic game with the rival interests of France and Spain, a game comparable to her domestic manipulation of rival factions. State-sanctioned privateering raids, led by Sir Francis Drake and others, on Spanish shipping and ports alternated with conciliatory gestures and peace talks. But by the mid-1580s it became increasingly clear that England could not avoid a direct military confrontation with Spain. Word reached London that the Spanish king, Philip II, had begun to assemble an enormous fleet that would sail to the Netherlands, join forces with a waiting Spanish army led by the duke of Parma, and then proceed to an invasion and conquest of Protestant England. Always reluctant to spend money, the queen had nonetheless authorized sufficient funds during her reign to maintain a fleet of maneuverable, well-armed fighting ships, to which could be added other vessels from the merchant fleet. When in July 1588 the Invincible Armada reached English waters, the queen's ships, in one of the most famous naval encounters of history, defeated the enemy fleet, which then in an attempt to return to Spain was all but destroyed by terrible storms.

The Invincible Armada

At the moment when the Spanish invasion was imminently expected, Elizabeth resolved to review in person a detachment of soldiers assembled at Tilbury. Dressed in a white gown and a silver breastplate, she rode through the camp and proceeded to deliver a celebrated speech. Some of her councillors, she said, had cautioned her against appearing before a large, armed crowd, but she did not and would not distrust her faithful and loving people. Nor was she afraid of Parma's army: "I know I have the body of a weak and feeble woman," Elizabeth declared, "but I have the heart and stomach of a king, and of a king of England too." She then promised, "in the word of a Prince," richly to reward her loyal troops, a promise that she characteristically proved reluctant to keep. The scene exemplifies many of the queen's qualities: her courage, her histrionic command of grand public occasions, her rhetorical blending of magniloquence and the language of love, her strategic identification with martial virtues considered male, and even her princely parsimony.

The queen's image. Elizabeth's parsimony did not extend to personal adornments. She possessed a vast repertory of fantastically elaborate dresses and rich jewels. Her passion for dress was bound up with political calculation and an acute self-consciousness about her image. She tried to control the royal portraits that circulated widely in England and abroad, and her appearances in public were dazzling displays of wealth and magnificence. Throughout her reign she moved restlessly from one of her palaces to another—Whitehall, Nonsuch, Greenwich, Windsor, Richmond, Hampton Court, and Oatlands—and availed herself of the hospitality of her wealthy subjects. On her journeys, known as royal progresses, she wooed her people and was received with lavish entertainments. Artists, including poets like Edmund Spenser and painters like Nicholas Hilliard, celebrated her in a variety of mythological guises—as Diana, the chaste goddess of the moon; Astraea, the goddess of justice; Gloriana, the queen of the fairies—and Elizabeth, in addition to adopting these fanciful roles, appropriated to herself some of the veneration that pious Englishmen had directed to the Virgin Mary.

"She imagined," wrote Francis Bacon a few years after the queen's death, "that the people, who are much influenced by externals, would be diverted by the glitter of her jewels, from noticing the decay of her personal attractions." Bacon's cynicism reflects the darkening tone of the last decade of Elizabeth's reign, when her control over her country's political, religious, and economic forces and over her representation of herself began to show severe strains. Bad harvests, persistent inflation, and unemployment caused hardship and a loss of public morale. Charges of corruption and greed led to widespread popular hatred of many of the queen's favourites to whom she had given lucrative and much-resented monopolies. A series of disastrous military attempts to subjugate the Irish culminated in a crisis of authority with her last great favourite, Robert Devereux, the proud Earl of Essex, who had undertaken to defeat rebel forces led by Hugh O'Neill, Earl of Tyrone. Essex returned from Ireland against the queen's orders, insulted her in her presence, and then made a desperate, foolhardy attempt to raise an insurrection. He was tried for treason and executed on Feb. 25, 1601.

The last decade

Elizabeth continued to make brilliant speeches, to exercise her authority, and to receive the extravagant compliments of her admirers, but she was, as Sir Walter Raleigh remarked, "a lady surprised by time," and her long reign was drawing to a close. She suffered from bouts of melancholy and ill health and showed signs of increasing debility. Her more astute advisers—among them Lord Burghley's son, Sir Robert Cecil, who had succeeded his father as her principal counselor—secretly entered into correspondence with the likeliest claimant to the throne, James VI of Scotland. On March 24, 1603, having reportedly indicated James as her successor, Elizabeth died quietly. The nation enthusiastically welcomed its new king. But in a very few years the English began to express nostalgia for the rule of "Good Queen Bess." Long before her death she had transformed herself into a powerful image of female authority, regal magnificence, and national pride, and that image has endured to the present.

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(S.J.G.)

Human Emotion

An emotion, as it is commonly known, is a distinct feeling or quality of consciousness, such as joy or sadness, that reflects the personal significance of an emotion-arousing event. In modern times the subject of emotion has become part of the subject matter of several scientific disciplines—biology, psychology, psychiatry, anthropology, and sociology. Emotions are central to the issues of human survival and adaptation. They motivate the development of moral behaviour, which lies at the very root of civilization. Emotions influence empathic and altruistic behaviour, and they play a role in the creative processes of the mind. They affect the basic processes of perception and influence the way humans conceive and interpret the world around them. Evidence suggests that emotions shape many other aspects of human life and human affairs. Clinical psychologists and psychiatrists often describe problems of adjustment and types of psychopathology as "emotional problems," mental conditions that an estimated 1 in 3 Americans, for example, suffers from during his or her lifetime.

The subject of emotion is studied from a wide range of views. Behaviorally oriented neuroscientists study the neurophysiology and neuroanatomy of emotions and the relations between neural processes and the expression and experience of emotion. Social psychologists and cultural anthropologists study similarities and differences among cultures by the way emotions are expressed and conceptualized. Philosophers are interested in the role of emotions in rationality, thought, character development, and values. Novelists, playwrights, and poets are interested in emotions as the motivations and defining features of fictional characters and as vehicles for communicating the meaning and significance of events.

This article will consider the meaning of emotions; the use of emotion concepts in literature and philosophy; the activation, structure, and functions of emotions as conceived by psychologists and neuroscientists; and the causes and consequences of emotions as reflected in individual experience and social relationships.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* section 433.

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Definitions and humanistic background

DEFINITIONS

Emotion has been defined as a particular psychological state of feeling, such as fear, anger, joy, and sorrow. The feeling often includes action tendencies and tends to trigger certain perceptual and cognitive processes. Most experts agree that emotion is a causal factor or influence in thoughts, actions, personalities, and social relationships.

The multilevel concept

The concept of emotion that will be developed here is a multiaspect, or multilevel, one, considering structure and functions at the levels of neurophysiology, emotion expression, and emotion experience (feeling). It should be noted, however, that not all of the numerous definitions that can be found in emotion literature fit into this multilevel concept. The definitions, which reflect differences in the interests and theoretical orientations of the authors, can be reduced to three categories concerned with structure and three concerned with functions. The three structural categories are the three levels, or aspects, that are included in the multilevel concept. The first of these categories of definition focuses on the neurophysiological processes underlying or accompanying emotions, the second on expression, or emotional behaviour, and the third on the subjective experience, or conscious aspect, of emotion.

Of the three categories of definition related to functions, the first defines emotions in terms of their adaptive or disruptive influences. The second category defines emotion in terms of motivation and considers it as part of the same class of phenomena that contains physiological drives, such as pain, thirst, and the need for elimination. The third category concerned with functions consists of definitions that attempt to distinguish between emotion and other psychological processes.

A multilevel definition of emotion essentially subsumes definitions that focus on one of the three structural categories of neural processes, expressive behaviour, and subjective experience, and elaborations and extensions of such a definition would consider concerns of the three categories related to functions. In summary, the foregoing consideration of definitions of emotion suggests that a multilevel concept comes closest to a consensus viewpoint among emotion theorists and provides a way of resolving the complex issue of definition. Thus, a specific emotion is a particular set of neural processes that gives rise to a particular configuration of expressive behaviours and a particular feeling state or quality of consciousness that has motivational and adaptive functions. Under some circumstances extremely intense emotion may become disruptive.

HUMANISTIC BACKGROUND

Orators, literary artists, and philosophers have recognized emotions as part of human nature since recorded history. Homer's *Iliad* contains vivid descriptions of the emotions of the characters; the goddess Athena frequently goes among Agamemnon's troops playing upon their emotions, attempting to allay their fears and bolster their courage for battle. Ancient philosophers discussed the emotions at length, and from these discussions it appears that the basic meanings of emotion concepts are timeless. For example,

Aristotle's views

in the *Rhetoric,* Aristotle described the significance, causes, and consequences of the experiences of anger, fear, and shame in much the same way as contemporary writers. He observed that anger is caused by undeserved slight, fear by the perception of danger, and shame by deeds that bring disgrace or dishonour. His understanding of the relations among emotions also has a modern ring. In contrasting the young and the old, he said of the young,

> And they are more courageous, for they are full of passion and hope, and the former of these prevents them fearing, while the latter inspires them with confidence, for no one fears when angry, and hope of some advantage inspires confidence.

Literature. The use of emotion words in literary works serves several purposes. They help define the motivations and personalities of the characters in a play or novel, and they help the reader to understand and identify with characters and to experience vicariously their emotions.

Shakespeare, for example, was a master at expressing emotion through his characters and eliciting emotions from the audience. His work also contains quite accurate descriptions of emotional expressions. An example in *Henry V* is the king's effort to ready his soldiers for battle:

> Then imitate the action of the tiger;
> Stiffen the sinews, summon up the blood,
> Disguise fair nature with hard-favour'd rage;
> Then lend the eye a terrible aspect;
> Let it pry through the portage of the head
> Like the brass cannon; let the brow o'erwhelm it
> As fearfully as doth a galled rock
> O'erhang and jutty his confounded base,
> Swill'd with the wild and wasteful ocean.
> Now set the teeth and stretch the nostril wide,
> Hold hard the breath and bend up every spirit
> To his full height.
>
> (Act III, scene 1)

James Joyce's use of emotion

In modern times James Joyce used emotion words and words with emotional connotation to powerful effect. In *A Portrait of the Artist as a Young Man,* much of Stephen Dedalus' mood and character are revealed in a few lines describing a time when he was drinking with his cronies and trying to overcome his sense of alienation from his father:

> His mind seemed older than theirs: it shone coldly on their strifes and happiness and regrets like a moon upon a younger earth. . . . Nothing stirred within his soul but a cold and cruel and loveless lust. His childhood was dead or lost and with it his soul capable of simple joys, and he was drifting amid life like the barren shell of the moon.

According to the literary critic Rosemarie Battaglia, the emotion-arousing words cold, cruel, loveless, dead, lost, and barren resonate with a sense of Stephen's withdrawal from his social world.

Other modern writers have made frank use of psychological concepts of emotion and emotion-related processes, particularly those introduced by Sigmund Freud. Thus, for example, the author's characters may be motivated by unconscious processes, feelings they cannot label and articulate because the fundamental underlying ideation associated with the feelings has been repressed.

Philosophy. Using Aristotle's system of causal explanation, the 16th-century British philosopher John Rainolds defined emotion as follows: the efficient cause of emotions is God, who implanted them; the material cause is good and evil human things; the formal cause is a commotion of the soul, impelled by the sight of things; and the final cause is seeking good and fleeing evil. The American philosopher L.D. Green's commentary on Rainolds' thesis indicates that Rainolds was not faithful to Aristotle's own discussions of emotion.

One thing that Aristotle did advocate was moderation of emotions, allowing them to have an effect only at the right time and in the right manner. Rainolds noted that the Aristotelian thinker Cicero saw emotions as beneficial—fear making humans careful, compassion and sadness leading to mercy, and anger whetting courage. These thoughts about emotion are similar to those of some modern theorists.

For Rainolds, the emotions are the active, energizing aspects of human nature. Although the intellect exercises control over emotions, intellect can have no impact without emotion. Rainolds was specifically concerned with the effects of emotion on rhetoric, but he saw rhetoric as a principal means of influencing human behaviour and affairs. He believed that

> the passions [emotions] must be excited, not for the harm they do but for the good, not so they twist the straight but that they straighten the crooked; so they ward off vice, iniquity, and disgrace; so that they defend virtue, justice, and probity.

Spinoza's idea of emotion and bodily change

Benedict de Spinoza in the 17th century described emotions in much the same way as Rainolds did, but he discussed them in relation to action rather than to language. He saw emotions as bodily changes that result in the amplification or attenuation of action and as processes that can facilitate or impede action. For Spinoza, emotion also included the ideas, or mental representations, of the bodily changes in emotion.

Blaise Pascal and David Hume reversed Rainolds' position by assuming the primacy of emotion in human behaviour. Hume said that reason is the slave of the passions (emotions), and Pascal observed in *Pensées* that "the heart has reasons that reason does not know." Although Hume believed that passions (emotions) rule reason or intellect, he thought the dominant passion should be moral sentiment. Some contemporary psychologists trace morality to empathy and empathy to discrete emotions including sadness, sorrow, compassion, and guilt.

Since Rainolds lectured on emotions at Oxford, philosophers have considered many questions related to emotions: Are they active or passive? Can they be explained by neurophysiological processes and reduced to material phenomena? Are they rational or nonrational? Are they voluntary or involuntary? Characterizing or categorizing emotions according to these dichotomies has resulted in yet other classifications or distinctions.

Ultimately, emotion concepts resist definition by way of dichotomous distinctions. Emotions are generally active and tend to generate action and cognition, but extreme fear may cause behavioral freezing and mental rigidity. Emotion can be explained on one level in terms of neurochemical processes and on another level in terms of phenomenology. Emotions are rational in the sense that they serve adaptive functions and make sense in terms of the individual's perception of the situation. They are nonrational in the sense that they can exist in the brain at the neurochemical level and in consciousness as unlabeled feelings that may be independent of cognitive-rational processes. Emotions are voluntary in that their expression in older children and adults is subject to considerable modification and control via cognition and action, and willful regulation of expression may result in regulation of emotion experience. Emotions are involuntary in that an effective stimulus elicits them automatically, without deliberation and conscious choice. Nowhere is this more evident than in infants and young children, who have little capacity to modulate or inhibit emotion by means of cognitive processes.

Rational and nonrational emotions

One contemporary American philosopher, Amélie O. Rorty, espouses a three-part causal history for emotions, which includes (1) the formative events in a person's past, including the development of habits of thought, (2) sociocultural factors, and (3) genetically determined sensitivities and patterns of response. These are essentially the same factors that are recognized by psychologists, who frequently reduce the list to two: (1) experience as mediated by culture and learning and (2) genetic determinants that unfold with ontogenetic development. The first of these two causal factors indicates that individual differences in interpretations of an event or situation lead to different emotions in different persons.

Some philosophers are concerned with the question of the rationality of emotion as judged on the basis of causes and consequences. One resolution is in terms of appropriateness: an emotion is appropriate if the reasons for it are adequate, regardless of the reasons against it. There may be a sense, however, in which emotions are intrinsically nonrational because they can come into a person's consciousness without that person having considered all of the relevant reasons for them. In the final analysis, caution should be used in judging the rationality of emotions.

James Hillman's conception

Another contemporary philosopher, James Hillman, has been notably effective in using classical philosophical principles to explain emotions. He has delineated 12 ways that emotion has been conceptualized in philosophy and psychology. These include conceptions of emotion as a distinct entity or trait, an accompaniment of instinct, energy for thought and action, a neurophysiological mechanism and process, mental representation, signal, conflict, disorder, and creative organization. This philosopher found each of these conceptions incomplete or incorrect and returned to Aristotle's system of four causes in an effort to integrate the information from each of the foregoing approaches to defining and studying emotions.

For Hillman, the efficient cause of emotion, described psychologically, consists of conscious or unconscious mental representations (perceptions, images, or thoughts) and conflicts between physiological or psychological systems or between a person and the environment. The efficient cause described physiologically includes genetic endowment and the neurochemical and hormonal processes involved in emotion activation. Hillman stated that the material cause of emotion is energy. He argued that matter, the ultimate source of energy, is relative and that emotion, as the psychological aspect of general energy, is going on all the time and is a two-way bridge uniting subject and object.

In considering the formal cause, one may see emotion as a pattern of neurophysiological and expressive behaviours and subject–object relations. Hillman concluded that, in a formal sense, emotion is a total pattern of the soul:

> Emotion is the soul as a complex whole, involving constitution, gross physiology, facial expression in its social context as well as actions aimed at the environment.

The final cause, or purpose, of emotion, according to Hillman, can be thought of in terms of what it achieves: survival (energy release, homeostatic regulation, and action on the stimulus and environment), signification (qualification of experience, expression, communication, and values), and improvement (emergence of energy into consciousness, facilitation of creative activity, and strengthening of the organization of self and behaviour). Hillman integrated these various descriptions of final cause in the concept of change. Emotion occurs in order to actualize change; "emotion itself is change."

HOW PSYCHOLOGY CONCEIVES EMOTIONS

In 1872, emotion studies received a boost in scientific status when Charles Darwin published his seminal treatise *The Expressions of the Emotions in Man and Animals.* Twelve years later, the American philosopher and psychologist William James, one of the pioneers of psychology in the United States, published what was to become a famous and controversial theory of emotions. In it James proposed that an arousing stimulus (such as a poignant memory or a physical threat) triggers internal physiological processes as well as external expressive and motor actions and that the feeling of these physiological and behavioral processes constitutes the emotion. Thus, people are happy because they smile, sad because they cry, angry because they frown, and afraid because they run from danger.

A few years later the Danish physician Carl Lange published a more constricted theory, maintaining that emotion is a function of the perception of changes in the visceral organs innervated by the autonomic nervous system. Although there were distinctively individual components in the theories of James and Lange, the theories became linked in the minds of psychologists and the combination became known as the James–Lange theory.

The James–Lange theory

The James–Lange theory was seriously challenged by the American physiologist Walter B. Cannon, who showed that, among other things, animals whose viscera were separated from the central nervous system still displayed emotion expression. Cannon contended that bodily changes were similar for most kinds of emotions, whereas the James–Lange theory implied a different bodily pattern of response for different emotions. The James–Lange theory has remained a more or less permanent fixture in behavioral science nevertheless, and most psychology textbooks summarize the theory and Cannon's criticisms of it. Some theories of emotion are classified as neo-Jamesian, and most theories can be identified or classified on the basis of their similarities and differences with the landmark James–Lange theory.

Psychological theories of emotion can be grouped into two broad categories—biosocial and constructivist. Although this system of categorization is an oversimplification, it provides a way for the student of emotion to get a perspective on a particular theory. A contemporary textbook, for example, describes 20 psychological theories of emotion, and there are many others that it does not consider.

Many of the differences between the two categories of emotion theory stem from different assumptions regarding the relative importance of genetics and life experiences. Biosocial theories assume that emotions are rooted in biological makeup and that genes are significant determinants of the threshold and characteristic intensity level of each basic emotion. In this view, emotional life is a function of the interaction of genetic tendencies and the evaluative systems, beliefs, and roles acquired through experience. Constructivist theories assume that genetic factors are inconsequential and that emotions are cognitively constructed and derived from experience, especially from social learning. The constructivists' crucible for emotions is formed by the interactions of the person with the environment, especially the social environment. Thus, according to the constructivists, emotions are a function of appraisals, or evaluations, of the world of culture, and of what is learned. (For examples of both types of theory and some of the research generated by each, see below *Contemporary approaches to emotion.*)

Biosocial and constructivist theories

The importance of emotions

The use of emotion concepts is common in literature and philosophy, as was discussed above, and there is widespread agreement among scientists that emotions are important in individual development, physical and mental health, and human relations. Experts in different disciplines emphasize different reasons for the importance of emotions.

EVOLUTIONARY-BIOLOGICAL PERSPECTIVES

Darwin and emotion expressions

Darwin included emotions, in particular emotion expressions, in his studies of evolution. He considered continuity or similarity of expression in animals and human beings as further evidence of human evolution from lower forms. His finding that certain emotion expressions are innate and universal was seen as evidence of the "unity of the several races." Thus, the expressions, or the language of the emotions, provide a means of communication among all human beings, regardless of culture or ethnic origin.

In his work *The Expression of the Emotions in Man and Animals,* Darwin made an explicit value judgment regarding the significance of emotion expressions:

> The movements of expression in the face and body, whatever their origin may have been, are in themselves of much importance for our welfare. They serve as the first means of communication between the mother and infant; she smiles approval, and thus encourages her child on the right path, or frowns disapproval. We readily perceive sympathy in others by their expression; our sufferings are thus mitigated and our pleasures increased; and mutual good feeling is thus strengthened. The movements of expression give vividness and energy to our spoken words. They reveal the thoughts and intentions of others more truly than do words, which may be falsified.

From his studies of emotion expressions, Darwin concluded that some emotion expressions were due to the "constitution of the nervous system," or our biological endowment. The implication is that these expressive movements are part of human nature and have played a role in survival and adaptation. Darwin thought other expressions were derived from actions that originally served biologically adaptive functions (*e.g.,* preparation for biting became the bared teeth of the anger expression). Although he noted that expressive movements may no longer serve biological functions, he made it quite clear that they serve critical social and communicative functions.

PSYCHOLOGICAL VIEWS

Significance of emotions

From the very beginning of scientific psychology, there were voices that spoke of the significance of emotions for human life. James believed that "individuality is founded in feeling" and that only through feeling is it possible "directly to perceive how events happen, and how work is actually done." The Swiss psychiatrist Carl Gustav Jung recognized emotion as the primal force in life:

> But on the other hand, emotion is the moment when steel meets flint and a spark is struck forth, for emotion is the chief source of consciousness. There is no change from darkness to light or from inertia to movement without emotion.

Psychologists did not rally to the Darwinian thesis on the evolutionary-adaptive functions of emotions in significant numbers until the 1960s. Several influential volumes following this theme were published in the 1960s and '70s. For example, the American psychologist Robert Plutchik echoed Darwinian principles in several of the postulates of his theory: emotions are present at all levels of animal life, and they serve an adaptive role in relation to survival issues posed by the environment.

The American psychologist Silvin Tomkins believed that the emotions constitute the primary motivational system for human beings. He held that even physiological drives such as hunger and sex obtain their power from emotions and that the energizing effects of emotion are necessary to sustain drive-related actions. In this way, he argued that emotions are essential to survival and adaptation.

Other theorists and researchers that follow the Darwinian principles of the survival value and adaptive value of emotions have emphasized their role in human development and in the development of social bonds, particularly mother–infant or parent–child attachment. These researchers have shown that even the very young infant has a repertoire of emotion expressions translatable into messages calling for nourishment and affection, both essential ingredients of healthy development. The distress expression is the infant's all-out cry for help, the sadness expression an appeal for empathy, and the smile an invitation to stimulating face-to-face interactions. (For discussion of empirical evidence of the importance of emotions in child development, social relations, cognitive processes, and mental health, see below *The functions of emotion.*)

Infant emotions

Contemporary approaches to emotion

Contemporary psychologists are concerned with the activation, or causes, of emotion, its structure, or components, and its functions or consequences. Each of these aspects can be considered from both a biosocial and a constructivist view. On the whole, biosocial theories have been relatively more concerned with the neurophysiological aspects of emotions and their roles as motivators and organizers of cognition and action. Constructivists have been relatively more concerned with explaining the causes of emotion at the experiential level and cognition-emotion relations in terms of cognitive–linguistic processes.

STRUCTURES AND PROCESSES OF EMOTION ACTIVATION

The question of precisely how an emotion is triggered has been one of the most captivating and controversial topics in the field. To address the question properly, one must break it down into more precise parts. Emotion activation can be divided into three parts: neural processes, bodily (physiological) changes, and mental (cognitive) activity.

While it is easy for people to think of things that make them happy or sad, it is not yet possible to explain precisely how the feelings of joy and sadness occur. Neuroscience has produced far more information about the processes leading to the physiological responses and expressive behaviour of emotion than about those that generate the conscious experience of emotion.

Neural processes. An emotion can be activated by causes and processes within the individual or by a combination of internal and external causes and processes. For example, within the individual, an infection can cause pain, and pain can activate anger.

The findings of neuroscience indicate that stimuli are evaluated for emotional significance when information from primary receptors (in the visual, tactual, auditory, or other sensory systems) travels along certain neural pathways to the limbic forebrain. Scientific data developed by Joseph E. LeDoux show that auditory fear conditioning involves the transmission of sound signals through the auditory pathway to the thalamus (which relays information) in the lower forebrain and thence to the dorsal amygdala (which evaluates information).

The brain's involvement

Evidence from neuroscience suggests that emotion activated by way of the thalamo-amygdala (subcortical) pathway results from rapid, minimal, automatic, evaluative processing. Emotion activated in this way need not involve the neocortex. Emotion activated by discrimination of stimulus features, thoughts, or memories requires that the information be relayed from the thalamus to the neocortex. Such a circuit is thought to be the neural basis for cognitive appraisal and evaluation of events.

This two-circuit model of the neural pathways in emotion activation has several important theoretical implications. The neurological evidence indicating that emotion can be activated via the thalamo-amygdala pathway is consistent with the behavioral evidence that very young infants respond emotionally to pain and that adults can develop preferences or make affective judgments in responding to objects before they demonstrate recognition memory for them. This suggests that in some instances humans may experience emotion before they reason why.

It might be expected that in early human development most emotion expressions derive from automatic, subcortical processing, with minimal cortical involvement. As cognitive capacities increase with maturation and learning, the neocortex and the cortico-amygdala pathway become more and more involved. By the time children acquire language and the capacity for long-term memory, they may process events in either or both pathways, with the subcortical pathway specializing in events requiring rapid response and the cortico-amygdala pathway providing evaluative information necessary for cognitive judgment and more complex coping strategies.

Physiological processes. Many theorists agree that feedback from physiological activity contributes to emotion activation. There is disagreement over the kind of feedback that is important. Some think that it is a visceral feedback—coming from the activity of the smooth-muscle organs such as the heart and stomach, which are innervated by the autonomic nervous system. Others believe that it is feedback from the voluntary, striated muscles, especially of the face, which are innervated by the somatic nervous system.

Cognitive processes. Constructivist theorists and researchers have been concerned with the causes of emotion at the cognitive-experiential level and with the relations between cognitive processes and emotion. This research has focused on two topics: the relations between appraisals, or evaluations, and emotions and the relations between causal attributions and emotions.

Magda B. Arnold was the first contemporary psychologist to propose that all emotions are a function of one's cognitive appraisal of the stimulus or situation. She maintained that before a stimulus can elicit emotion it has to be appraised as good or bad by the perceiver. She described the appraisal that arouses emotion as concrete, immediate, undeliberate, and not the result of reflection. Her position was adopted and elaborated by others, some of whom assumed that cognitive activity, whether in the form of primitive evaluative perception or symbolic processes, is a necessary precondition of emotion. Biosocial and constructivist theorists agree that cognition is an important determinant of emotion and that emotion–cognition relations merit continued research.

Emotion appraisal

Research by the American psychologists Phoebe C. Ellsworth and Craig A. Smith on the relations between appraisals and specific emotions show that people tend to appraise situations in terms of elements such as pleasantness, anticipated effort, certainty, responsibility, control, legitimacy, and perceived obstacle. Researchers have found that each discrete emotion tends to be associated with a distinctive combination of appraisals. For example, a perceived obstacle (barrier to a goal) that is due to

someone else's responsibility is associated with anger, a perceived obstacle that is the person's own responsibility is associated with guilt, and a perceived obstacle characterized by uncertainty is associated with fear. This study was based on subjects' retrospective accounts of emotion-eliciting situations, and therefore the data cannot confirm the view that appraisal causes emotion. However, the assumption that emotion and appraisal are causally related seems reasonable.

Another approach to explaining the causes of emotions is that of attribution theory. The central idea of this theory, according to the American psychologist Bernard Weiner, is that the perceptions of the causes of events can be characterized in three principal ways which affect many emotional experiences. The perceived causes of events (*e.g.,* success and failure) are characterized by their locus (internal or external to the person), stability (a trait of the person or a temporary condition), and controllability (under the person's control or not).

Attribution theory

Research has shown that different patterns of causal attribution are associated with different emotions, including anger, guilt, shame, and the more complex phenomena of pity, pride, gratitude, and hopelessness. Pity is attributed to the perception of uncontrollable and stable causes—people feel pity for a person who has an affliction due to a genetic defect or accident. Anger is attributed to external and controllable events—people feel anger when an affront or injury is caused by someone's lack of concern or thoughtlessness. Guilt is attributed to the perception of internal and controllable causes—people feel guilt for wrongdoing they could have avoided. Children aged five to 12 understand the emotional consequences of revealing the causes of their actions; they know that their teachers might be angry at their failure if they have not tried hard enough and that teachers might feel pity for students who lack the ability to learn efficiently and perform well.

Psychologists researching cognitive activation have studied the relations between the ways people cope with stressful encounters and the emotions they experience after their efforts to resolve the problems. In one study emotions were assessed by asking subjects to indicate the extent to which they experienced emotions on four scales: worried/fearful, disgusted/angry, confident, and pleased/happy. Coping was assessed by subjective ratings on eight scales: confrontive coping ("stood my ground and fought"), distancing ("didn't let it get to me"), self-control ("tried to keep my feelings to myself"), seeking social support ("talked to someone"), accepting responsibility ("criticized myself"), escape–avoidance ("wished the situation would go away"), planful problem solving ("changed or grew as a person"), and positive reappraisal. Four of these ways of coping were associated with the quality of emotion that followed the effort to cope. Planful problem solving and positive reappraisal tended to increase happiness and confidence and to decrease disgust and anger. Obversely, the subjects reported that confrontation and distancing techniques increased their disgust and anger and decreased their happiness and confidence. Because these data were retrospective, there can be no firm conclusion that a particular way of coping causes a particular emotion experience. Nevertheless, the observed relations among ways of coping and subsequent emotion experiences are reasonable and in line with theoretical expectations.

Coping with emotions

The controversy as to whether some cognitive process is a necessary antecedent of emotion may hinge on the definition of terms, particularly the definition of cognition. If cognition is defined so broadly that it includes all levels or types of information processing, then cognition may confidently be said to precede emotion activation. If those mental processes that do not involve mental representation based on learning or experience are excluded from the concept of cognition, then cognition so defined does not necessarily precede the three-week-old infant's smile to the high-pitched human voice, the two-month-old's anger expression to pain, or the formation of the affective preferences (likes or dislikes) in adults.

Multimodal theory. Evidence suggests that a satisfactory model of emotion activation must be multimodal. Emotions can, as indicated above, be activated by such pre-cognitive processes as physiological states, motor mimicry (imitation of another's movements), and sensory processes and by numerous cognitive processes, including comparison, matching, appraisal, categorization, imagery, memory, attribution, and anticipation. Further, all emotion activation processes are influenced by a variety of internal and external factors.

THE STRUCTURE OF EMOTIONS

In the discussion of the structure of emotions it is not always possible to ignore the function of emotions, which is discussed in the following section. The separation, however, is conducive to sorting out the complex field of emotions.

Biosocial and constructivist views

Both biosocial and constructivist theories of emotions acknowledge that an emotion is a complex phenomenon. They generally agree that an emotion includes physiological functions, expressive behaviour, and subjective experience and that each of these components is based on activity in the brain and nervous system. As noted above, some theorists, particularly those of the constructivist persuasion, hold that an emotion also involves cognition, an appraisal or cognitive-evaluative process that triggers the emotion and determines or contributes to the subjective experience of the emotion.

The physiological component. The physiological component of emotion has been a lively topic of research since Cannon challenged the James–Lange theory by showing that feedback from the viscera has little effect on emotional expression in animals. Cannon's studies and criticisms were regarded by many as too narrow, failing to, among other things, consider the possible role of feedback from striated muscle systems of the face and body.

Findings of neuroscience

Role of the nervous system. Since the popularization of the James–Lange theory of emotion, the physiological component of emotion has been traditionally identified as activity in the autonomic nervous system and the visceral organs (*e.g.,* the heart and lungs) that it innervates. However, some contemporary theorists hold that the neural basis of emotions resides in the central nervous system and that the autonomic nervous system is recruited by emotion to fulfill certain functions related to sustaining and regulating emotion experience and emotion-related behaviour. Several findings from neuroscience support this idea. Neuroanatomical studies have shown that the central nervous system structures involved in emotion activation can exert direct influences on the autonomic nervous system. For example, efferents from the amygdala to the hypothalamus may influence activity in the autonomic nervous system that is involved in defensive reactions. Further, there are connections between pathways innervating facial expression and the autonomic nervous system. Studies have shown that patterns of activity in this system vary with the type of emotion being expressed.

Roles of the brain hemispheres. There is some evidence that the two hemispheres of the brain are related differently to emotion processes. Early evidence suggested that the right (or dominant) hemisphere may be more adept than the left at discriminating among emotional expressions. Later research using electroencephalography elaborated this initial conclusion, suggesting that the right hemisphere may be more involved in processing negative emotions and the left hemisphere more involved in processing positive emotions.

The expressive component. The expressive component of emotion includes facial, vocal, postural, and gestural activity. Expressive behaviour is mediated by phylogenetically old structures of the brain, which is consistent with the notion that they served survival functions in the course of evolution.

Involvement of brain structures. Emotion expressions involve limbic forebrain structures and aspects of the peripheral nervous system. The facial and trigeminal nerves and receptors in facial muscles and skin are required in expressing emotion and in facilitating sensory feedback from expressive movements.

Early studies of the neural basis of emotion expression showed that aggressive behaviour can be elicited from a cat after its neocortex has been removed and suggested

that the hypothalamus is a critical subcortical structure mediating aggression. Later research indicated that, rather than the hypothalamus, the central gray region of the midbrain and the substantia nigra may be the key structures mediating aggressive behaviour in animals.

Importance of facial expression

Neural pathways of facial expression. Of the various types of expressive behaviour, facial expression has received the most attention. In human beings and in many nonhuman primates, patterns of facial movements constitute the chief means of displaying emotion-specific signals. Whereas research has provided much information on the neural basis of emotional behaviours (*e.g.*, aggression) in animals, little is known about the brain structures that control facial expression.

The peripheral pathways of facial emotion expression consist of the seventh and fifth cranial nerves. The seventh, or facial, nerve is the efferent (outward) pathway; it conveys motor messages from the brain to facial muscles. The fifth, or trigeminal, nerve is the afferent (inward) pathway that provides sensory data from movements of facial muscles and skin. According to some theorists, it is the trigeminal nerve that transmits the facial feedback which contributes to the activation and regulation of emotion experience. The impulses for this sensory feedback originate when movement stimulates the mechanoreceptors in facial skin. The skin is richly supplied with such receptors, and the many branches of the trigeminal nerve detect and convey the sensory impulses to the brain.

The innateness and universality of emotion expressions. More than a century ago Darwin's observations and correspondence with friends living in different parts of the world led him to conclude that certain emotion expressions are innate and universal, part of the basic structure of emotions. Contemporary cross-cultural and developmental research has given strong support to Darwin's conclusion, showing that people in literate and preliterate cultures have a common understanding of the expressions of joy, surprise, sadness, anger, disgust, contempt, and fear. Other studies have suggested that the expressions of interest and shyness and the feelings of shame and guilt may also be innate and universal.

The experiential component. There is general agreement that various stimuli and neural processes leading to an emotion result not only in physiological reactions and expressive behaviour but also in subjective experience. Some biosocial theorists restrict the definition of an emotion experience to a feeling state and argue that it can be activated independently of cognition. Constructivist theorists view the experiential component of emotion as having a cognitive aspect. The issue regarding the relation between emotion feeling states and cognition remains unresolved, but it is widely agreed that emotion feeling states and cognitive processes are typically highly interactive.

Emotion experiences, the actual feelings of joy, sadness, anger, shame, fear, and the like, do not lend themselves to objective measurement. All research on emotion experience ultimately depends on self-reports, which are imprecise. There are few instances where feelings and words are perfectly matched. Yet, most students of emotions, whether philosopher or neuroscientist, ultimately want to explain emotion experience.

Neural basis of emotion experience

The physiological structure of emotion experience. Little is known about the neural basis of emotion experience. Critical reviews have shown that there is little evidence to support the position that activity in the autonomic nervous system provides the physiological basis for emotion experience. However, there is some evidence to support the hypothesis that sensory feedback from facial expression contributes to emotion experience.

Cognitive models of emotion experience have influenced conceptions of the underlying neural processes. Explanations of emotions in terms of appraisal and attributional processes led some researchers to suggest that conscious experiences of emotions derive from the cognitive processes that underlie language. This led to the hypothesis that emotion experiences involve interactions between limbic forebrain areas and the areas of the neocortex that mediate language and language-based cognitive systems. However, this view does not take into account the possibility that emotions occur in preverbal infants and may be mediated in adults by unconscious or nonlinguistic mental processes, such as imagery.

Action tendencies in emotion experiences. Both constructivist and biosocial theorists have emphasized that emotions include action tendencies. The experience, or feeling, of a given emotion generates a tendency to act in a certain way. For example, in anger the tendency is to attack and in fear to flee. Whether a person actually attacks in anger or flees in fear depends on the individual's methods of emotion regulation and the circumstances.

THE FUNCTIONS OF EMOTIONS

In academic discussions of the functions of emotions the focus is usually on the phenomenological, or experiential, aspect of emotions. For purposes of this discussion, however, the functions of emotions are examined in terms of the three structural components—physiological, expressive, and experiential.

Structural components of functions

Physiological functions. The functions of physiological activity that is mediated by the autonomic nervous system and that accompanies states of emotion can be considered as part of the individual's effort to adapt and cope, but, of course, physiological as well as cognitive reactions in extreme emotion usually require regulation (expressed through cognitive processes and expressive behaviour) in order for coping activities to be effective. For example, adaptation to situations that elicit a less extreme emotion such as interest require a quite different physiological and behavioral activity than do situations that elicit intense anger or fear. The heart-rate deceleration and quieting of internal organs that occur in interest facilitate the intake and processing of information, whereas heart-rate acceleration in intense anger and fear prepares the individual to cope by more active means, whether through shouting, physical actions, or various combinations of the two.

Functions of emotion expressions. Emotion expressions have three major functions: they contribute to the activation and regulation of emotion experiences; they communicate something about internal states and intentions to others; and they activate emotions in others, a process that can help account for empathy and altruistic behaviour.

Feedback of facial expression

Role of expressions in emotion experiences. In *The Expression of the Emotions in Man and Animals* Darwin clearly revealed his belief that even voluntary emotion expression evoked emotion feeling. He wrote: "Even the simulation [expression] of an emotion tends to arouse it in our minds." Thus, Darwin's idea suggested that facial feedback (sensations created by the movements of expressive behaviour) activate, or contribute to the activation of, emotion feelings. A number of experiments have provided substantial evidence that intentional management of facial expression contributes to the regulation (and perhaps activation) of emotion experiences. Most evidence is related not to specific emotion feelings but to the broad classes of positive and negative states of emotion. There is, therefore, some scientific support for the old advice to "smile when you feel blue" and "whistle a happy tune when you're afraid."

Darwin was even more persuasive when speaking specifically of the regulation of emotion experience by self-initiated expressive behaviour. He wrote:

> The free expression by outward signs of an emotion intensifies it. On the other hand, the repression, as far as this is possible, of all outward signs softens our emotions.

Experiments by more contemporary researchers on motivated, self-initiated expressive behaviours have shown that, if people can control their facial expression during moments of pain, there will be less arousal of the autonomic nervous system and a diminution of the pain experience.

Role of expressions in communicating internal states. The social communication function of emotion expressions is most evident in infancy. Long before infants have command of language or are capable of reasoning, they can send a wide variety of messages through their facial expressions. Virtually all the muscles necessary for facial expression of basic emotions are present before birth. Through the use of an objective, anatomically based system for coding the separate facial muscle movements, it

has been found that the ability to smile and to facially express pain, interest, and disgust are present at birth; the social smile can be expressed by three or four weeks; sadness and anger by about two months; and fear by six or seven months. Informal observations suggest that expressions indicative of shyness appear by about four months and expressions of guilt by about two years.

The expressive behaviours are infants' primary means of signaling their internal states and of becoming engaged in the family and larger human community. Emotion expressions help form the foundation for social relationships and social development. They also provide stimulation that appears to be necessary for physical and mental health.

Mother–infant relations through emotion expression

Role of expressions in motivating response. One- and three-day-old infants cry in response to other infants' cries but not to a computer-generated sound that simulates crying. Infants as young as two or three months of age respond differently to different expressions by the mother. The information an infant obtains from the mother's facial expressions mediates or regulates a variety of infant behaviours. For example, most infants cross a modified "visual cliff" (an apparatus that was originally used in depth perception study, consisting of a glass floor that gives the illusion of a drop-off) if their mother stands on the opposite side and smiles, but none cross if she expresses fear.

Facial expressions, particularly of sadness, may facilitate empathy and altruistic behaviour. Darwin thought facial expressions evoked empathy and concluded that expression-induced empathy was inborn. Research has shown that, when mothers display sadness expressions, their infants also demonstrate more sadness expressions and decrease their exploratory play. Infants under two years of age respond to their mother's real or simulated expressions of sadness or distress by making efforts to show sympathy and provide help.

Functions of emotion experiences. Psychologists who adopt a strong behaviourist position deny that emotion experiences are matters for scientific inquiry. In contrast, some biosocial theories hold that emotion feelings must be studied because they are the primary factors in organizing and motivating human behaviour. According to these theories, most of the functions attributed to emotion expressions, such as empathy and altruism, are dependent on the organizing and motivating properties of underlying emotion feelings. Emotion experiences have several other functions.

Commonality of emotion experience

Research has shown that people in widely different literate and preliterate cultures not only recognize basic emotion expressions but also characterize and label them with semantically equivalent terms. It seems reasonable to assume that the common feeling state of a given emotion generates the cues for the cognitive processes that result in universal emotion concepts. Of course, if researchers include contextual factors, such as societal taboos, in their description of an emotion experience, they then find differences across cultures. In any case, although the feeling of a given emotion, say fear, may be constant, people within and across cultures learn to be afraid of quite different things and to cope with fear in different ways.

Experiential influence on cognitive processes. Several lines of research have shown that induced emotion affects perception, learning, and memory. In one study, conducted by Carroll E. Izard and his students, subjects were made happy or angry and then shown happy and angry faces and friendly and hostile interpersonal scenes in a stereoscope. Happy subjects perceived more happy faces and friendly interpersonal scenes, and angry subjects perceived more angry faces and hostile interpersonal scenes. In this case, emotion apparently altered the basic perceptual process. In another study subjects were made happy or sad and then given happy and sad information about fictional persons and later asked to give their impressions and make judgments about the fictional characters. Overall, happy subjects reported more favourable impressions and positive judgments than did sad subjects. These studies provide evidence for the common wisdom that happy people are more likely to see the world through rose-coloured glasses.

Experiential facilitation of empathy and altruism. An extensive series of studies indicated that positive emotion feelings enhance empathy and altruism. It was shown by the American psychologist Alice M. Isen that relatively small favours or bits of good luck (like finding money in a coin telephone or getting an unexpected gift) induced positive emotion in people and that such emotion regularly increased the subjects' inclination to sympathize or provide help.

Experiential relation to increased creativity. Several studies have demonstrated that positive emotion facilitates creative problem solving. One of these studies showed that positive emotion enabled subjects to name more uses for common objects. Another showed that positive emotion enhanced creative problem solving by enabling subjects to see relations among objects that would otherwise go unnoticed. A number of studies have demonstrated the beneficial effects of positive emotion on thinking, memory, and action in preschool and older children.

Effects of positive emotion

Explanation of the functions of emotion experiences. There are two kinds of factors that contribute to the enhancing effects of positive emotion on perception, learning, creative problem solving, and social behaviour. Two factors, emphasized by cognitive-social theorists, are related to cognitive processes. First, positive emotion cues positive material in memory, and, second, positive material in memory is more extensive than neutral and negative material. The second set of factors, emphasized by biosocial theorists, are related to the intrinsic motivational and organizational influences of emotion and to the particular characteristics of the subjective experience of positive emotion. For example, these theorists maintain that the experience of joy is characterized by heightened self-esteem and self-confidence. These qualities of consciousness increase the receptibility to information and the flexibility of mental processes. Biosocial theorists consider that the positive emotion induced by experimental manipulations and experimental tasks includes the emotion of interest, which is characterized by curiosity and the desire to explore and learn. The concepts emphasized by biosocial and cognitive-social theories may be seen as complementary.

EMOTIONS AND ADAPTATION

The results of many of the experiments discussed above indicate that emotions have motivational and adaptive properties. Perhaps the most convincing demonstrations of this come from studies showing that emotions influence perception, learning, and memory and empathic, altruistic, and creative actions.

Some theorists have viewed emotions more negatively, seeing them as disorganizing and disrupting influences. Researchers in this tradition have also viewed emotions as transient, episodic states. These ideas were fueled by a research emphasis on "emergency emotions," such as rage and panic. These researchers might agree that, although such emotions may serve an adaptive function under certain circumstances, in many situations they can lead to behaviours that prove to be maladaptive and even fatal. As was indicated above, however, emotion expressions can serve critical functions in mother–infant communication and attachment, and emotion experiences, or feeling states, facilitate learning and empathic, altruistic, and creative behaviour.

Biological adaptations

Although psychologists generally favour viewing emotions as having motivating, organizing, and adaptive functions, the conditions under which emotions become maladaptive warrant further research. Extreme anger and fear can bring about large changes in the activities of internal organs innervated by the autonomic nervous system. When such arousal repeatedly involves the sympathetic nervous system and the hormones of the medulla of the adrenal gland, the individual may develop resistance to mental and physical disorders. When there is repeated arousal involving the sympathetic nervous system and the hormones of the cortex of the adrenal gland, the individual may experience adverse effects.

Problems of adaptation and mental health can also be conceived as attributable not to the emotions but to the

way a person thinks and acts. For example, if a person decides to break a moral code and consequently feels guilty, the guilt may be adaptive in that it can provide motivation for making amends. In this framework psychological problems or disorders arise because the individual fails to respond appropriately to the emotion's motivational cues while the emotion is still at low or moderate intensity.

THE REGULATION OF EMOTIONS

Several beliefs and attitudes have contributed to the idea that emotions should be brought under rather tight control. Historically, some religious and philosophical literature has treated human passion, a concept which included emotions, as an evil force that could contaminate or even destroy the mind or soul. In this tradition passions became associated with sin and wrongdoing, and their rigorous control was thus a sign of goodness. Even in this tradition, however, some negative emotions were exempt from tight control—guilt as a result of wrongdoing and righteous indignation toward moral transgressions.

Changing views of emotion regulation. Traditionally, scientists have given far more attention to negative emotions and their control than to positive ones. The focus on negative emotions has continued among clinical psychologists and psychiatrists, who are concerned with relieving depression and anxiety. However, as parents have long recognized, there is also a need to regulate positive emotions when, for example, children are having fun at someone else's expense or while neglecting chores and homework.

Developmental processes in emotion regulation. Of central importance in emotion regulation are developmental processes that enable children, as they mature, to exercise an increasingly greater control over affective responses. For example, before an infant can regulate the innate affective behaviour patterns elicited by acute pain, maturation of neural inhibitory mechanisms is required. Further control is realized through techniques that result from cognitive development and socialization, processes involving both maturation and learning.

Regulation in infants

In a study of responses of two- to 19-month-old infants to the pain of diphtheria-tetanus-pertussis (DTP) inoculation, it was found that the physical distress expression occurred as the initial response in all infants at the ages of two, four, and seven months (the ages at which the first three DTPs were administered). The physical distress expression is an all-out emergency response, a cry for help that dominates the physical and mental capacities of the infant. Beginning at the age of four months and accelerating rapidly between seven and 19 months, the infants became capable of greatly reducing the duration of the physical distress expression. As the duration of the physical distress expression decreased, that for anger expression increased. By 19 months of age, 25 percent of the infants were able to inhibit the distress expression completely. It was inferred that these developmental changes are adaptive for the relatively more capable toddler: whereas the physical distress expression in the younger subjects is all-consuming, anger mobilizes energy for defense or escape.

Other factors in emotion regulation. Several other factors are observable in emotion or mood regulation. First, there is neurochemical regulation by means of naturally occurring hormones and neurotransmitters. Regulation is also attained through psychoactive drugs, many of which were developed to control the prevalent psychological disorders of anxiety and depression. A substantial body of research has shown that anxiety and depression are associated with chemical imbalances in the brain and nervous system. Psychoactive drugs help to correct these imbalances.

Neurochemical regulation

Socialization processes, especially child-rearing practices, influence emotion regulation. Attempts by parents, teachers, and other adults to control emotions may be aimed either at the level of expression or experience or both. Parents may try to control their child's anger expressions before they culminate in "temper tantrums." A father may try to control his son's expressions of fear of bodily injury because he anticipates the shame of his son being seen as a coward. In considering the net effect of socialization on emotion regulation, it is necessary to weigh the effects that the child's unique genetic makeup may contribute to the process.

Cognitive-social theories point to cognitive processes as means of controlling emotion. According to this approach, if it is possible for people to change the way they make appraisals and attributions about the nature and cause of events, their emotion experiences can be changed. This could be manifested, for instance, in a reduction in self-blame and an alteration in negative concepts and outlooks. That cognitive therapy and cognitive techniques for controlling depressive and aggressive behaviour have achieved some success is testimony to the validity of the idea of cognitive control of emotion. That they sometimes fail indicates that it is no panacea and that other factors may be necessary for emotion regulation. As discussed above, theory and empirical data support the notion that expressive behaviour, which is under voluntary control, can be used to regulate emotions.

EMOTIONS, TEMPERAMENT, AND PERSONALITY

Most theorists agree that emotion thresholds and emotion responsiveness are part of the infrastructure of temperament and personality. There has, however, been little empirical research on the relations among measures of emotions, dimensions of temperament, and personality traits.

Emotions and temperament. Most theories of temperament define at least one dimension of temperament in terms of emotion. Two theories maintain that negative emotions form the core of one of the basic and stable dimensions of temperament. Another suggests that each of the dimensions of temperament is rooted in a particular discrete emotion and that these dimensions form the emotional substrate of personality characteristics. For example, proneness to anger would influence the development of aggressiveness, and the emotion of interest would account for the temperament trait of persistence.

Dimensions of temperament

Emotions and personality. A number of major personality theories, such as theories of temperament, identify dimensions or traits of personality in terms of emotions. For example, the German-born British psychologist Hans J. Eysenck has proposed three fundamental dimensions of personality: extroversion–introversion, neuroticism, and psychoticism. Extroversion–introversion includes the trait of sociability, which can also be related to emotion (*e.g.*, interest, as expressed toward people, versus shyness). Neuroticism includes emotionality defined, as in temperament theory, as nonspecific negative emotional responsiveness. Psychoticism may represent emotions gone awry or the absence of emotions appropriate to the circumstances.

Eysenck's fundamental dimensions

Several studies have shown that measures of positive emotionality and negative emotionality are independent, are not inversely related, and have stability over time. Further, it has been shown that positive and negative emotionality have different relations with symptoms of psychological disorders. For example, negative emotionality correlates positively with panic attack, panic-associated symptoms and obsessive-compulsive symptoms; that is, the higher the degree of negative emotion, the more likely that the attack or symptoms will occur. Conversely, positive emotionality correlates negatively with these phenomena. Although several of the same negative emotions characterize both the anxiety and depressive disorders, a lack of positive emotion experiences is more characteristic of depression than of anxiety.

Continuity of emotion expressiveness. Some studies have shown that specific emotions, identified in terms of expressive behaviour and physiological functions, have stability. One study showed that a child's expression of positive and negative emotion was consistent during the first two years of life. Other studies have shown stability of wariness or fear responses, indicating that a child who is fearful at one age is likely to be fearful in comparable situations at a later age. In a study of infants' responses to the pain of DTP inoculation, it was found that the child's anger expression indexes at ages two, four, and six months accurately predicted his or her anger expression in the inoculations at 19 months of age. Similar results were obtained for the sadness expression.

A study of mother–infant interaction and separation found that infants' expression at three to six months of age were accurate predictors of infant emotion expressive patterns at nine to 12 months of age. Emotion expression patterns have also shown continuity from 13 to 18 months of age during brief mother–infant separation.

Conclusion

The emotions are central to the issues of modern times, but perhaps they have been critical to the issues of every era. Poets, prophets, and philosophers of all ages have recognized the significance of emotions in individual life and human affairs, and the meaning of a specific emotion, at least in the context of verbal expression, seems to be timeless. Although art, literature, and philosophy have contributed to the understanding of emotion experiences throughout the ages, modern science has provided a substantial increase in the knowledge of the neurophysiological basis of emotions and their structure and functions.

Research in neuroscience and developmental psychology suggests that emotions can be activated automatically and unconsciously in subcortical pathways. This suggests that humans often experience emotions without reasoning why. Such precognitive information processing may be continuous, and the resulting emotion states may influence the many perceptual-cognitive and behavioral processes (such as perceiving, thinking, judging, remembering, imagining, and coping) that activate emotions through pathways involving the neocortex.

Pre-cognitive aspects

The two recognized types of emotion activation have important implications for the role of emotions in cognition and action. Subcortical, automatic information processing may provide the primitive data for immediate emotional response, whereas higher-order cognitive information processing involving the neocortex yields the evaluations and attributions necessary for the appropriate emotions and coping strategy in a complex situation.

Biosocial and constructivist theories agree that perception, thought, imagery, and memory are important causes of emotions. They also agree that once emotion is activated, emotion and cognition influence each other. How people feel affects what they perceive, think, and do, and vice versa.

Emotions have physiological, expressive, and experiential components, and each component can be studied in terms of its structure and functions. The physiological component influences the intensity and duration of felt emotion, expressions serve communicative and sociomotivational functions, and emotion experiences (feeling states) influence cognition and action.

Research has shown that certain emotion expressions are innate and universal and have significant functions in infant development and in infant–parent relations and that there are stable individual differences in emotion expressiveness. Emotion states influence what people perceive, learn, and remember, and they are involved in the development of empathic, altruistic, and moral behaviour and in basic personality traits.

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(C.E.I.)

Encyclopaedias and Dictionaries

For more than 2,000 years encyclopaedias have existed as summaries of extant scholarship in forms comprehensible to their readers. The word encyclopaedia, of Greek origin (*enkyklopaideia*), at first meant a circle or a complete system of learning—that is, an all-around education. When Rabelais used the term in French for the first time in *Pantagruel* (chapter 20), he was still talking of education. It was Paul Scalich, a German writer and compiler, who was the first to use the word to describe a book in the title of his *Encyclopaedia; seu, orbis disciplinarum, tam sacrarum quam prophanum epistemon* . . . ("Encyclopaedia; or, Knowledge of the World of Disciplines, Not Only Sacred but Profane . . . "), issued at Basel in 1559. The many encyclopaedias that had been published prior to this time either had been given fanciful titles (*Hortus deliciarum*, "Garden of Delights") or had been simply called "dictionary." The word dictionary has been widely used as a name for encyclopaedias, and Scalich's pioneer use of encyclopaedia did not find general acceptance until Denis Diderot made it fashionable with his historic French encyclopaedia, although cyclopaedia was then becoming fairly popular as an alternative term.

An outline of the scope and history of encyclopaedias is essentially a guide to the development of scholarship, for encyclopaedias stand out as landmarks throughout the centuries, recording much of what was known at the time of publication. Many homes have no encyclopaedia, very few have more than one, yet in the past two millennia several thousand encyclopaedias have been issued in various parts of the world, and some of these have had many editions. No library has copies of them all; if it were possible to collect them, they would occupy many miles of shelf space. But they are worth preserving—even those that appear to be hopelessly out-of-date—for they contain many contributions by a large number of the world's leaders and scholars.

"Dictionary" is used to describe a wide variety of reference works. Basically, a dictionary lists a set of words with information about them. The list may attempt to be a complete inventory of a language or may be only a small segment of it. A short list, sometimes at the back of a book, is often called a glossary. When a word list is an index to a limited body of writing, with references to each passage, it is called a concordance. Theoretically, a good dictionary could be compiled by organizing into one list a large number of concordances. A word list that consists of geographic names only is called a gazetteer.

The word lexicon designates a wordbook, but it also has a special abstract meaning among linguists, referring to the body of separable structural units of which the language is made up. In this sense, a preliterate culture has a lexicon long before its units are written in a dictionary. Scholars in England sometimes use "lexis" to designate this lexical element of language.

The compilation of a dictionary is lexicography; lexicology is a branch of linguistics in which, with the utmost scientific rigour, the theories that lexicographers use in the solution of their problems are developed.

The common phrase "dictionary order" takes for granted that the alphabetical order will be followed, and yet the alphabetical order has been called a tyranny that makes dictionaries less useful than they might be if compiled in some other order. The assembling of words into groups related by some principle, as by their meanings, can be done, and such a work is often called a thesaurus or synonymy. Such works, however, need an index for ease of reference, and it is unlikely that alphabetical order will be superseded except in specialized works. A monolingual dictionary has both the word list and the explanations in the same language, whereas bilingual or multilingual (polyglot) dictionaries have the explanations in another language or different languages. The word dictionary is also extended, in a loose sense, to reference books with entries in alphabetical order, such as a dictionary of biography, a dictionary of heraldry, or a dictionary of plastics.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 735, and the *Index*.

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ENCYCLOPAEDIAS

The meaning of the word encyclopaedia has changed considerably during its long history. Today most people think of an encyclopaedia as a multivolume compendium of all available knowledge, complete with maps and a detailed index, as well as numerous adjuncts such as bibliographies, illustrations, lists of abbreviations and foreign expressions, gazetteers, and so on. They expect it to include biographies of the great men and women of the present as well as those of the past, and they take it for granted that the alphabetically arranged contents will have been written in their own language by many people and will have been edited by a highly skilled and scholarly staff; nevertheless, not one of these ingredients has remained the same throughout the ages. Encyclopaedias have come in all sizes from a single 200-page volume written by one man to giant sets of 100 volumes or more. The degree of coverage of knowledge has varied according to the time and country of publication. Illustrations, atlases, and bibliographies have been omitted from many encyclopaedias, and for a long time it was not thought fitting to include biographies of living persons. Indexes are a late addition, and most of the early ones were useless. Alphabetical arrangement was as strongly opposed as the use of any language but Latin, at least in the first 1,000 years of publication in the West, and skilled group editorship has a history of scarcely 200 years.

In this article the word encyclopaedia has been taken to include not only the great general encyclopaedias of the past and the present but all types of works that claim to provide in an orderly arrangement the essence of "all that is known" on a subject or a group of subjects. This includes dictionaries of philosophy and of American history as well as volumes such as *The World Almanac and Book of Facts,* which is really a kind of encyclopaedia of current information.

The nature of encyclopaedias

In the *Speculum majus* ("The Greater Mirror"; completed 1244), one of the most important of all encyclopaedias, the French medieval scholar Vincent of Beauvais maintained not only that his work should be perused but that the ideas it recorded should be taken to heart and imitated. Alluding to a secondary sense of the word *speculum* ("mirror"), he implied that his book showed the world what it is and what it should become. This theme, that encyclopaedias can contribute significantly to the improvement of mankind, recurs constantly throughout their long history. A Catalan ecclesiastic and scholastic philosopher, Ramon Llull, regarded the 13th-century encyclopaedias, together with language and grammar, as instruments for the pursuit of truth. Domenico Bandini, an Italian humanist, planned his *Fons memorabilium universi* ("The Source of Noteworthy Facts of the Universe") at the beginning of the 15th century to provide accurate information on any subject to educated men who lacked books and to give edifying lessons to guide them in their lives. Francis Bacon believed that the intellect of the 17th-century individual could be refined by contact with the intellect of the ideal man. Another Englishman, the poet and critic Samuel Taylor Coleridge, was well aware of this point of view and said in his "Preliminary Treatise on Method" (1817) that in the *Encyclopaedia Metropolitana,* which he was proposing to create, "our great objects are to exhibit the Arts and Sciences in their Philosophical harmony; to teach Philosophy in union with Morals; and to sustain Morality by Revealed Religion." He added that he intended to convey methodically "the pure and unsophisticated knowledge of the past . . . to aid the progress of the future." The Society for the Diffusion of Useful Knowledge declared in *The Penny Cyclopaedia* (1833–43) that, although most encyclopaedias attempted to form systems of knowledge, their own would in addition endeavour to "give such general views of all great branches of knowledge, as may help to the formation of just ideas on their extent and relative importance, and to point out the best sources of complete information."

In *De disciplinis* ("On the Disciplines"; 1531) the Spanish humanist Juan Luis Vives emphasized the encyclopaedia's role in the pursuit of truth. In Germany of the early 19th century the encyclopaedia was expected to provide the right or necessary knowledge for good society. Probably the boldest claim was that of Alexander Aitchison, who said that his new *Encyclopaedia Perthensis* (1796–1806) was intended to supersede the use of all other English books of reference.

Greek and Roman concepts

All these ideas were a far cry from the Greek concept, deriving from Plato, that in order to think better it is necessary to know all, and from the Roman attitude of the advisability of acquiring all useful knowledge in order to carry out one's tasks in life competently. The present concept of the encyclopaedia as an essential starting point from which one can embark on a voyage of discovery, or as a point of basic reference on which one can always rely, is little more than two centuries old.

The prose form has usually been accepted as the only suitable vehicle for the presentation of the text of an encyclopaedia, though *L'Image du monde* ("The Image of the World"; 1245?)—attributed by some to Gautier de Metz, a French poet and priest, and by others to a Flemish theologian, Gossuin—was written in French octosyllabic verse. It has also been generally accepted that an encyclopaedia should adopt a straightforward, factual approach. Even so, the Spanish writer Alfonso de la Torre, in his *Visio delectable* ("Delightful Vision"; *c.* 1484), adopted the allegorical approach of a child receiving instruction from a series of maidens named Grammar, Logic, Rhetoric, and so on.

The alphabetically arranged encyclopaedia has a history of less than 1,000 years, most of the encyclopaedias issued before the introduction of printing into Europe having been arranged in a methodical or classified form. The early compilers of encyclopaedias held, as Coleridge was to hold, that "to call a huge unconnected miscellany of the *omne scibile,* in an arrangement determined by the accident of initial letters, an encyclopaedia, is the impudent ignorance of your Presbyterian bookmakers!" Today several encyclopaedias still retain the classified form of arrangement.

There has never been any general agreement on the way in which the contents of an encyclopaedia should be arranged. In Roman times the approach was usually practical, with everyday topics such as astronomy and geography coming first, while the fine arts were relegated to the end of the work. The Roman statesman and writer Cassiodorus, however, in his 6th-century *Institutiones,* began with the Scriptures and the church and gave only brief attention to such subjects as arithmetic and geometry. St. Isidore of Seville, educated in the classical tradition, redressed the balance in the next century in his *Etymologiarum sive originum libri XX* ("Twenty Books on Origins, or Etymologies"), commonly called *Etymologiae,* giving pride of place to the liberal arts and medicine, the Bible and the church coming later, but still preceding such subjects as agriculture and warfare, shipping and furniture. The earliest recorded Arabic encyclopaedia, compiled by the Arab philologist and historian Ibn Qutayba, had a completely different approach, beginning with power, war, and nobility, and ending with food and women. A later Persian encyclopaedia, compiled in 975–997 by the Persian scholar and statesman al-Khwārizmī, started with jurisprudence and scholastic philosophy, the more practical matters of medicine, geometry, and mechanics being relegated to a second group labelled "foreign knowledge." The general trend in classification in the Middle Ages is exemplified by Vincent of Beauvais's *Speculum majus,* which was arranged in three sections: "Naturale"—God, the creation, man; "Doctrinale"—language, ethics, crafts, medicine; "Historiale"—world history. The encyclopaedists were, however, still uncertain

of the logical sequence of subjects, and although there were many who started with theological matters, there were just as many who preferred to put practical topics first.

A turning point came with Francis Bacon's plan for his uncompleted *Instauratio magna* ("Great Instauration"; 1620) in which he eschewed the endless controversies in favour of a three-section structure, including "External Nature" (covering such topics as astronomy, meteorology, geography, and species of minerals, vegetables, and animals), "Man" (covering anatomy, physiology, structure and powers, and actions), and "Man's Action on Nature" (including medicine, chemistry, the visual arts, the senses, the emotions, the intellectual faculties, architecture, transport, printing, agriculture, navigation, arithmetic, and numerous other subjects).

Arrangements of the contents

In his plan Bacon had achieved more than a thoroughly scientific and acceptable arrangement of the contents of an encyclopaedia; he had ensured that the encyclopaedists would have a comprehensive outline of the scope of human knowledge that would operate as a checklist to prevent the omission of whole fields of human thought and endeavour. Bacon so profoundly altered the editorial policy of encyclopaedists that even 130 years later Diderot gratefully acknowledged his debt in the prospectus (1750) of the *Encyclopédie*. Because every later encyclopaedia was influenced by Diderot's work, the guidance of Bacon still plays its part today.

By courtesy of the trustees of the British Museum: photograph, R.B. Fleming & Co.



Engraved title page from the first edition of Francis Bacon's *Instauratio magna*, published in London, 1620.

Coleridge, who was very much impressed by Bacon's scheme, in 1817 drew up a rather different table of arrangement for the *Encyclopaedia Metropolitana*. It comprised five main classes: Pure Sciences, Formal (philology, logic, mathematics) and Real (metaphysics, morals, theology); Mixed and Applied Sciences, the Mixed being mechanics, hydrostatics, pneumatics, optics, and astronomy and the Applied being experimental philosophy, the fine arts, the useful arts, natural history, and application of natural history; Biographical and Historical, chronologically arranged; Miscellaneous and Lexicographical, with a gazetteer and a philosophical and etymological lexicon. The fifth class was to be an analytical index.

Coleridge's influence

Although Coleridge's classification was altered by the publisher, and although the *Metropolitana* was an impressive failure, the ideas for it had a lasting influence. Even though nearly all encyclopaedias today are arranged alphabetically, the classifications of Bacon and Coleridge still enable editors to plan their work with regard to an assumed hierarchy of the various branches of human knowledge.

The concept of alphabetical order was well known to both the Greeks and Romans, but the latter made little use of it. Neither the Greeks nor the Romans employed it for encyclopaedia arrangement, with the exception of Sextus Pompeius Festus in his 2nd-century *De verborum significatu* ("On the Meaning of Words"). St. Isidore's encyclopaedia was classified, but it included an alphabetically arranged etymological dictionary. The 10th- or 11th-century encyclopaedic dictionary known as *Suidas* was the first such work to be completely arranged alphabetically, but it had no influence on succeeding encyclopaedias, although glossaries, when included, were so arranged. Bandini's *Fons memorabilium universi* ("The Source of Noteworthy Facts of the Universe"), though classified, used separate alphabetical orders for more than a quarter of its sections, and the Italian Domenico Nani Mirabelli's *Polyanthea nova* ("The New Polyanthea"; 1503) was arranged in one alphabetical sequence. These were rare exceptions, however; the real breakthrough came only with the considerable number of encyclopaedic Latin-language dictionaries that appeared in the early 16th century, the best known of which is a series of publications by the French printer Charles Estienne. The last of the great Latin-language encyclopaedias arranged in alphabetical order was *Encyclopaedia* (1630) by the German Protestant theologian and philosopher Johann Heinrich Alsted. The publication of *Le Grand Dictionnaire historique* ("The Great Historical Dictionary"; 1674) of Louis Moréri, a French Roman Catholic priest and scholar, confirmed public preference both for the vernacular and the alphabetically arranged encyclopaedia; this choice was emphasized by the success of the posthumous *Dictionnaire universel* (1690) by the French lexicographer Antoine Furetière.

From time to time important attempts have been made to reestablish the idea of the superiority of the classified encyclopaedia. Coleridge saw the encyclopaedia as a vehicle for enabling man to think methodically. He felt that his philosophical arrangement would "present the circle of knowledge in its harmony" and give a "unity of design and of elucidation." He did agree that his appended gazetteer and English dictionary would best be arranged alphabetically for ease of reference. By then, however, alphabetical arrangement had too strong a hold, and it was not until 1935 that a new major classified encyclopaedia began to appear—the *Encyclopédie française* ("French Encyclopaedia"), founded by Anatole de Monzie. The Dutch *Eerste nederlandse systematisch ingerichte encyclopaedie* ("First Dutch Systematic and Comprehensive Encyclopaedia"; 1946–52) had a classification that was in almost reverse order of that of the *Encyclopédie française*, but it is clear that behind both works lies a philosophical concept of the order and main divisions of knowledge that is influenced by both Bacon and Coleridge. The Spanish *Enciclopedia labor* (1955–60) and the *Oxford Junior Encyclopaedia* (1948–56) followed systems of arrangement that were closer to the French than to the Dutch example.

Trivium and quadrivium

From earliest times it had been held that the trivium (grammar, logic, rhetoric) and the quadrivium (geometry, arithmetic, astronomy, music) were essential ingredients in any encyclopaedia. Even as late as 1435 Alfonso de la Torre began his *Visió delectable* in almost that exact order, and only when he had laid these foundations did he proceed to the problems of science, philosophy, theology, law, and politics. Thus the seven liberal arts were regarded by the early encyclopaedists as the very mathematics of human knowledge, without a knowledge of which it would be foolish to proceed. This idea survived to a certain extent in Coleridge's classification; he stated that grammar and logic provide the rules of speech and reasoning, while

mathematics opens mankind to truths that are applicable to external existence.

When Louis Shores became editor in chief of *Collier's Encyclopedia* in 1962, he said that he considered the encyclopaedia to be "one of the few generalizing influences in a world of overspecialization. It serves to recall that knowledge has unity." This echoes the view of the English novelist H.G. Wells, that the encyclopaedia should not be "a miscellany, but a concentration, a clarification, and a synthesis." The Austrian sociologist Otto Neurath in the same year suggested that a proposed new international encyclopaedia of unified science should be constructed like an onion, the different layers enclosing the "heart"—comprising in this case the foundations of the unity of science.

Even a brief survey of contemporary encyclopaedia publishing is enough to make clear that, as the trivium and quadrivium and the topically classified encyclopaedias that they influenced receded further and further into history, there arose a number of modern encyclopaedists concerned with the importance of making a restatement of the unity of knowledge and of the consequent interdependence of its parts. Though most encyclopaedists were willing to accept the essential reference-book function of encyclopaedias and the role of an alphabetical organization in carrying out that function, they became increasingly disturbed about the emphasis on the fragmentation of knowledge that such a function and such an organization encouraged. A number looked for ways of enhancing the educational function of encyclopaedias by reclaiming for them some of the values of the classified or topical organizations of earlier history.

Notable among the results of such activities was the 15th edition of *Encyclopædia Britannica* (1974), which was designed in large part to enhance the role of an encyclopaedia in education and understanding without detracting from its role as a reference book. Its three parts (*Propædia,* or *Outline of Knowledge; Micropædia,* or *Ready Reference and Index;* and *Macropædia,* or *Knowledge in Depth*) represented an effort to design an entire set on the understanding that there is a circle of learning and that an encyclopaedia's short informational articles on the details of matter within that circle as well as its long articles on general topics must all be planned and prepared in such a way as to reflect their relation to one another and to the whole of knowledge. The *Propædia* specifically was a reader's version of the circle of learning on which the set had been based and was organized in such a way that a reader might reassemble in meaningful ways material that the accident of alphabetization had dispersed.

Encyclopaedias in general

THE ROLE OF ENCYCLOPAEDIAS

Of the various types of reference works—who's whos, dictionaries, atlases, gazetteers, directories, and so forth—the encyclopaedia is the only one that can be termed self-contained. Each of the others conveys some information concerning every item it deals with; only the encyclopaedia attempts to provide coverage over the whole range of knowledge, and only the encyclopaedia attempts to offer a comprehensive summary of what is known of each topic considered. To this end it employs many features that can help in its task, including pictures, maps, diagrams, charts, and statistical tables. It also frequently incorporates other types of reference works. Several modern encyclopaedias, from the time of Abraham Rees's *New Cyclopaedia* (1802–20) and the *Encyclopédie méthodique* ("Systematic Encyclopaedia"; 1782–1832) onward, have included a world atlas and a gazetteer, and language dictionaries have been an intermittent feature of encyclopaedias for most of their history.

Biographical material

Most modern encyclopaedias since the *Universal-Lexicon* (1732–50) of the Leipzig bookseller Johann Heinrich Zedler have included biographical material concerning living persons, though the first edition of *Encyclopædia Britannica* (1768–71) had no biographical material at all. In their treatment of this kind of information, however, they differ from the form of reference work that limits itself to the provision of salient facts without comment. Similarly, with dictionary material, some encyclopaedias provide foreign-language equivalents as well.

An English lexicographer, Henry Watson Fowler, wrote in the preface to the first edition (1911) of *The Concise Oxford Dictionary of Current English* that a dictionary is concerned with the uses of words and phrases and with giving information about the things for which they stand only so far as current use of the words depends upon knowledge of those things. The emphasis in an encyclopaedia is much more on the nature of the things for which the words and phrases stand. Thus the encyclopaedic dictionary, whose history extends as far back as the 10th- or 11th-century *Suidas,* forms a convenient bridge between the dictionary and the encyclopaedia, in that it combines the essential features of both, embellishing them where necessary with pictures or diagrams, at the same time that it reduces most entries to a few lines that can provide a brief but accurate introduction to the subject.

Interrelations. An encyclopaedia does not come into being by itself. Each new work builds on the experience and contents of its predecessors. In many cases the debt is acknowledged: the German publisher Friedrich Arnold Brockhaus bought the bankrupt encyclopaedia of Gotthelf Renatus Löbel in 1808 and converted it into his famous *Conversations-Lexikon*; but Jesuits adapted Antoine Furetière's *Dictionnaire universel* without acknowledgment in their *Dictionnaire de Trévoux* (1704). Classical writers made many references to their predecessors' efforts and often incorporated whole passages from other encyclopaedias. Of all the many examples, the *Cyclopaedia* (1728) of the English encyclopaedist Ephraim Chambers has been outstanding in its influence, for Denis Diderot's and Abraham Rees's encyclopaedias would have been very different if Chambers had not demonstrated what a modern encyclopaedia could be. In turn, the publication of *Encyclopædia Britannica* was stimulated by the issue of the French *Encyclopédie.* Almost every subsequent move in encyclopaedia making is thus directly traceable to Chambers' pioneer work.

The intended audience

Readership. Encyclopaedia makers have usually envisaged the particular public they addressed. Cassiodorus wrote for the "instruction of simple and unpolished brothers"; the Roman statesman Cato wrote for the guidance of his son; Gregor Reisch, prior of the Carthusian monastery of Freiburg, addressed himself to "Ingenuous Youth"; the Franciscan encyclopaedist Bartholomaeus Anglicus wrote for "ordinary" people; the German professor Johann Christoph Wagenseil wrote for children; and Herrad of Landsberg, abbess of Hohenburg, wrote for her nuns. *Encyclopædia Britannica* was designed for the use of the curious and intelligent layman. The editor of *The Columbia Encyclopedia* in 1935 tried to provide a work compact enough and written simply enough to serve as a guide to the "young Abraham Lincoln." The Jesuit Michael Pexenfelder (1670) made his intended audience clear enough by writing his *Apparatus Eruditionis* ("Apparatus of Learning") in the form of a series of conversations between teacher and pupil. St. Isidore addressed himself to the needs not only of his former pupils in the episcopal school but also to all the priests and monks for whom he was responsible. At the same time, he hoped to provide the newly converted population of Spain with a national culture that would enable it to hold its own in the Byzantine world.

Contributors. In sympathy with many of their various ends, many scholars have contributed to encyclopaedias. Not all their contributions are known, however, because until the mid-to-late 20th century it was not the custom to sign articles. It is known that the English encyclopaedist John Harris enlisted the help of scientists such as John Ray and Sir Isaac Newton for his *Lexicon Technicum* (1704) and that Rees's *New Cyclopaedia* (1802–20) included articles on music by the English organist and music historian Charles Burney and on botany by the English botanist Sir J.E. Smith. Illustrious Frenchmen such as Voltaire, Rousseau, Condorcet, Montesquieu, and Georges Boulanger contributed to the *Encyclopédie*; Thomas Macaulay, T.E. Lawrence, and more than 100 recipients of Nobel Prizes—including Marie Curie and Albert Einstein—to the *Britannica*; the Scottish physicist Sir David

Brewster and the Danish physicist Hans Christian Ørsted to *The Edinburgh Encyclopaedia* (1808–30); the English astronomer Sir William Herschel and the English mathematician and mechanical genius Charles Babbage to the *Metropolitana*; the Russian communist leader Lenin to the "Granat" encyclopaedia; and the dictator Benito Mussolini to the *Enciclopedia italiana*.

Language. The language of Western encyclopaedias was almost exclusively Latin up to the time of the first printed works. As with most scholarly writings, the use of Latin was advantageous because it made works available internationally on a wide scale and thus promoted unlimited sharing of information. On the other hand, it made the contents of encyclopaedias inaccessible to the great majority of people. Consequently, there was from the early days on a movement to translate the more important encyclopaedias into various vernaculars. Honorius Inclusus' *Imago mundi* ("Image of the World"; *c.* 1122) was rendered into French, Italian, and Spanish; Bartholomaeus Anglicus' *De proprietatibus rerum* ("On the Characteristics of Things"; 1220–40) into English; the Dominican friar Thomas de Cantimpré's *De natura rerum* ("On the Nature of Things"; *c.* 1228–44) into Flemish and German; and Vincent of Beauvais's *Speculum majus* ("The Greater Mirror") into French, Spanish, German, Dutch, and Catalan. In later years the more successful encyclopaedias were translated from one vernacular into another. Louis Moréri's encyclopaedia, *Le Grand Dictionnaire historique,* was translated into both English and German. The German *Brockhaus* appeared in a Russian translation (1890–1907), and the French *Petit Larousse* had several foreign-language editions. Nevertheless, an encyclopaedia, however successful in its own country, may find acceptance in another country far from easy.

Translations of Latin encyclopaedias

The contemporary world. Encyclopaedias have often reflected fairly accurately the civilization in which they appeared; that this was deliberate is shown by the frequency with which the earlier compilers included such words as *speculum* ("mirror"), *imago* ("image"), and so forth in their titles. Thus as early as the 2nd century the Greek Sophist Julius Pollux was already defining current technical terms in his *Onomastikon.* In the 13th century Vincent of Beauvais quoted the ideas of both pagan and Christian philosophers freely and without differentiation, for their statements often agreed on questions of morals. In doing so, he reflected the rapidly widening horizons of a period that saw the founding of so many universities. Bartholomaeus Anglicus devoted a considerable part of his work to psychology and medicine. "Theophilus" (thought to be Roger of Helmarshausen, a Benedictine monk) as early as the 12th century gave a clear and practical account in his *De diversis artibus* ("On Diverse Arts") of contemporary processes used in painting, glassmaking and decoration, metalworking, bone carving, and the working of precious stones, even listing the necessary tools and conditions for successful operations. Pierre Bayle, a French philosopher and critic, showed in his *Dictionnaire historique et critique* ("Historical and Critical Dictionary"; 1697) how the scientific renaissance of the previous 40 years had revolutionized contemporary thought. To every detail he applied a mercilessly scientific and inquiring mind that challenged the assumptions and blind reverence for authority that had characterized most of his predecessors.

Treatment of practical matters in encyclopaedias

At that point in history, much attention was being paid to practical matters: the statesman Jean-Baptiste Colbert himself directed the French Académie des Sciences (1675) to produce a work that eventually appeared as the *Description et perfection des arts et métiers* ("Description and Perfection of the Arts and Crafts"; 1761). The German Meyer's *Grosses Conversations-Lexicon* from the first edition (1840–55) onward paid particular attention to scientific and technical developments, and the *Encyclopedia Americana,* aided by the *Scientific American,* strengthened its coverage in this area from 1911 onward. In its very first edition the *Encyclopædia Britannica* included lengthy articles containing detailed instructions on such topics as surgery, bookkeeping, and many aspects of farming. Similarly, *The New Cyclopaedia,* in the early 19th century, incorporated articles on subjects such as candle making and coach building. The outstanding example of a completely contemporary encyclopaedia was, of course, the *Encyclopédie,* in which the philosopher Denis Diderot and the mathematician and philosopher Jean Le Rond d'Alembert and their friends set out to reject much of the heritage of the past in favour of the scientific discoveries and the more advanced thought of their own age. Their decision in this respect was both intellectually and commercially successful; since that time every edition of any good encyclopaedia has the additional merit of being a valuable source for the thought and attitudes of the people for whom it was published.

Encyclopaedias and politics. All great encyclopaedia makers have tried to be truthful and to present a balanced picture of civilization as they knew it, although it is probable that no encyclopaedia is totally unbiased. A great encyclopaedia is inevitably a sign of national maturity and, as such, it will often pay tribute to the ideals of its country and its times. The first Hungarian encyclopaedia, János Apáczai Csere's *Magyar encyclopaedia* (1653–55), was mostly a summary of what was available in foreign works, but the *Révai nagy lexikona* ("Révai's Great Lexicon"; 1911–35) was a handsome tribute to Hungary's emergence as a country in its own right, just as the *Enciklopedija Jugoslavije* (first published 1955–71) did full justice to the advances made by what was then Yugoslavia in the mid-20th century. The supreme example of an encyclopaedia that set out to present the best possible image of its people and the wealth and stature of their culture is undoubtedly the *Enciclopedia italiana* (1929–36). Mussolini's contribution of an article on fascism indicates the extent to which the work might be regarded as an ideological tool, but, in fact, most of its contents are admirably international and objective in approach. The various encyclopaedias of the former Soviet Union occupy many feet of shelf space, with the later editions each devoting one complete volume to the Soviet Union in all its aspects. Though successive editions were notable for the obvious political factors that were responsible for the inclusion and exclusion of entries for famous nationals according to the state of their acceptance or condemnation by the existing regime, many critics felt that the last edition, the first volume of which was issued in 1970, was somewhat less ideological than any of the others in this regard.

Diderot, the editor, and André-François Le Breton, the publisher, faced such opposition from both church and state in their publication of the *Encyclopédie* (1751–65) that many of the volumes were secretly printed, and the last 10 were issued with a false imprint. In the early part of the 19th century, *Brockhaus* was condemned by the Austrian censor, and in 1950 its 11th edition was branded as reactionary by the East German government. Nor was political censorship the only form of oppression in the world of encyclopaedias. Antoine Furetière, on issuing his prospectus (1675) for his *Dictionnaire universel,* found his privilege to publish cancelled by the French government at the request of the Académie Française, which accused him of plagiarizing its own dictionary. The Leipzig book trade, fearing that publication of Johann Heinrich Zedler's huge *Universal-Lexikon* (1732–50) might put them out of business, made such difficulties that Zedler thought it best to issue his work in Halle.

Opposition to encyclopaedias

The reader's needs. People look to encyclopaedias to give them an adequate introduction to a topic that interests them. Many expect the encyclopaedia to omit nothing and to include consideration of all controversial aspects of a subject. Encyclopaedia makers of the past assumed that there was a large public willing to read through an entire encyclopaedia if it was not too large. In the 18th century, for example, there was a good market for pocket-size compendia for the traveller, or for the courtier to browse in as he waited for an audience. Thus, although most encyclopaedias are multivolume works, there are many small works ranging from the *Didascalion* of the scholastic philosopher and mystic theologian Hugh of Saint-Victor (*c.* 1128), through Gregor Reisch's *Margarita philosophica* (1496) and the French writer Pons-Augustin Alletz' *Petite Encyclopédie* (1766), to C.T. Watkins' *Portable Cyclopaedia* (1817). The last was issued by a remarkable publisher,

Sir Richard Phillips, who realized the great demand for pocket-size compendia and drove a thriving trade in issuing a number of these; he is thought to have written large sections of these himself.

Royalty and encyclopaedias. Most of the classic Chinese encyclopaedias owe their existence to the patronage of emperors. In the West, the Roman scholar Pliny dedicated his *Historia naturalis* ("Natural History") to the emperor Titus; Julius Pollux dedicated his *Onomastikon* to his former pupil, the Roman emperor Commodus, whereas the Byzantine philosopher and politician Michael Psellus dedicated his *De omnifaria doctrina* ("On All Sorts of Teaching") to his former pupil the emperor Michael VII Ducas, ruler of the Eastern Roman Empire. Gervase of Tilbury, an English ecclesiastic, compiled his *Otia imperialia* ("Imperial Pastimes") for the Holy Roman emperor Otto IV, and Alfonso de la Torre prepared his *Visió delectable* for Prince Carlos of Viana. St. Isidore dedicated his encyclopaedia to the Visigothic king Sisebut, and the French king Louis IX patronized Vincent of Beauvais's *Speculum majus.* Nor did kings eschew the work of compiling encyclopaedias. The emperor Constantine VII of the Eastern Roman Empire was responsible for a series of encyclopaedias, and Alfonso X of Spain organized the making of the *Grande e general estoria* ("Great and General History").

Editorial censorship

Contents and authority. The extent to which readers have been dependent on editorial decisions concerning not only what to include but also what to exclude has yet to be explored in detail. For example, Vincent of Beauvais rarely mentioned the pagan and Christian legends that were so popular in his day. The anonymous compiler of the scholarly *Compendium philosophiae* ("Compendium of Philosophy"; *c.* 1316) was careful to omit the credulous tales that appeared in contemporary bestiaries. For many centuries it was not considered right to include biographies of men and women who were still alive. And the early Romans, such as Cato the Censor, rejected much of Greek theoretical knowledge, regarding it as a dangerous foreign influence and believing with the Stoics that wisdom consisted in living according to nature's precepts.

Whatever the compiler did decide to include had a far-reaching influence. Pliny's vast *Historia naturalis* has survived intact because for so many centuries it symbolized human knowledge, and even the "old wives' tales" it injudiciously included were unquestioningly copied into many later encyclopaedias. The influence of St. Isidore's work can be traced in writings as late as Sir John Mandeville's travels (published in French between 1357 and 1371) and the English poet John Gower's 14th-century *Confessio amantis* ("A Lover's Confession"). Honorius' *Imago mundi* is known to have influenced some of the German medieval chronicles and the Norse saga of Olaf Tryggvason. The main source of classics such as the *Roman de la rose,* the Alexander romances, Archbishop Giovanni da Colonna's *Liber de viris illustribus* ("Book Concerning Illustrious Men"), and the recorded lives of the saints can be traced to the *Speculum majus.* The direct and indirect influence of the critical encyclopaedias of Pierre Bayle and Denis Diderot is, of course, incalculable.

EDITING AND PUBLISHING

The length of encyclopaedias and encyclopaedic articles. There always have been and there still are a number of successful one-volume encyclopaedias. Outstanding examples in the 20th century included *The Columbia Encyclopedia,* the *Petit Larousse, Hutchinson's New Twentieth Century Encyclopedia,* and the *Random House Encyclopedia.* In the Random House set the contents were divided into two sections, a *Colorpedia,* composed of relatively lengthy articles dealing with broad topics, and an *Alphapedia,* composed of concise entries on very specific subjects. Some booksellers and publishers confirm that there is, however unreasonably, a certain amount of public prejudice against the single-volume form, and that most people prefer a multivolume work. Throughout the entire history of encyclopaedias there has been much variation in the number of volumes. Many of the Chinese encyclopaedias have been very much larger than any Western work. Pliny's *Historia naturalis* comprised about 2,500 chapters, Zedler's *Universal-Lexicon* was planned for 12 volumes and eventually filled 64; the publishers of the *Encyclopédie* were faced with a lawsuit (1768–78) for producing a 26-volume encyclopaedia instead of the 10 volumes they had promised; Johann Samuel Ersch and Johann Gottfried Gruber's German *Allgemeine Encyclopädie* ("General Encyclopaedia") had already reached 167 volumes at the time of its discontinuance; and the major Soviet encyclopaedia consisted of more than 50 volumes. Today most encyclopaedias range between 20 and 30 volumes, occupying between three and four feet of shelf space. Thus the modern encyclopaedia appears smaller than its 19th-century counterpart, but, in fact, the content may be greater because the thick mat paper of Victorian times has been replaced by a thinner paper capable of reproducing coloured and black-and-white halftone illustrations with sharp definition.

Even more noticeable than variations in the number of volumes in encyclopaedias has been an even greater variation in the average lengths of articles within those volumes. The 11th edition of the *Encyclopædia Britannica* contained almost twice as many articles as the last significant edition before it, but it contained only 15 or 16 percent more words. The difference had to do with editorial considerations regarding the matter of fragmentation. Although most of the major encyclopaedias of the past had devoted considerable space to any topic of major importance, there was increasing recognition in the 19th century that an alternative method of treatment would be to break large subjects into their constituent subtopics for alphabetical distribution throughout the set. Those who favoured this more fragmented approach argued that by focussing on the smaller part of the whole, the editors could facilitate the user's search for specific information and that the liberal provision of cross-references would facilitate a recombination of the fragments by those interested in the bigger picture. Against this practice, it was argued that most cross-references are not followed up by most readers, that the shorter fragmented pieces work against a correct understanding of the larger subject, and that fragmentation inevitably involved a great amount of repetition of basic information throughout all of the related articles. Nevertheless, *Brockhaus, Meyer, Larousse,* and other encyclopaedias of the shorter-entry type have had and continue to have a strong following.

Authorship by one individual

Authorship. The first encyclopaedia makers had no doubts concerning their ability to compile their works single-handedly. Cassiodorus, Honorius Inclusus (or Solitarius), and Vincent of Beauvais fully justified this attitude, though their task was largely that of the anthologist. Vincent and many other encyclopaedists employed both scribes and scholars to help them in their work, but, once the encyclopaedia reached the stage of independent writing, it was clear that the editorial task was going to become more complex. Even so, some of the later pocket encyclopaedias—such as the English bookseller John Dunton's mediocre *Ladies' Dictionary* (1694), *An Universal History of Arts and Sciences* (1745) by the French-born Englishman Chevalier Denis de Coëtlogon, and the popular *Allgemeines Lexicon* (1721) by the Prussian scholar Johann Theodor Jablonski—were substantially or almost wholly the work of a single-author; such items are, however, negligible.

John Harris, an English theologian and scientist, may have been one of the first to enlist the aid of experts, such as the naturalist John Ray and Sir Isaac Newton, in compiling his *Lexicon Technicum* ("Technical Lexicon"; 1704). Johann Heinrich Zedler, in his *Universal-Lexicon* (1732–50), went further by enlisting the help of two general editors, supported by nine specialist editors, the result being a gigantic work of great accuracy. The French *Encyclopédie,* the largest encyclopaedia issued at that time, inevitably had many contributors, although the French writer Voltaire said that Diderot's collaborator, the Chevalier Louis de Jaucourt (aided by secretaries), contributed about three-quarters of the articles in that work. The pattern for future encyclopaedias was established: for any substantial work it would be necessary not only to have contributions from the experts of the day, but it would also be essential to have subject editors who could supervise the

coverage and content in each area of knowledge. With little alteration, this system prevails today.

Encyclopaedia adjuncts. The readers of modern encyclopaedias are rarely aware of the numerous aids that have been provided to make their search for information so easy and efficient. Only when recourse is had to one of the older encyclopaedias does the reader become conscious of the advances that have been made. In former days it was often difficult to distinguish between one article and the next, because distinctive headings or inset titles or the use of boldface was rare. Nor was the necessity for running titles or alphabetical notations at the head of the pages fully appreciated. Even more troublesome was the problem of the arrangement of entries for several persons of the same name; reference to the older encyclopaedias under such headings as "Henry," "John," or "Louis"—names held by both princes and religious potentates—will show how little the art of acceptable arrangement was understood.

Arrangement of articles

Cross-references and bibliographies. Cross-references are an essential feature of the modern encyclopaedia; they date back at least as far as Bandini's 14th-century *Fons memorabilium universi*, but it was Brockhaus who introduced an ingenious system of using arrows instead of the words "see also." *The Columbia Encyclopedia* achieved the same effect by printing in small capital letters the words under which additional information could be found. Some encyclopaedias devote one volume to each letter of the alphabet or indicate the division between letters by thumb-indexing or some other means. In CD-ROMs, DVDs, and online encyclopaedias, cross-references are hyperlinked and provide virtually instantaneous movement throughout the database. In established encyclopaedias the bibliographies for individual articles are usually the result of careful editorial consultation with the writer and with librarians.

Indexes. Undoubtedly the major adjunct of the modern encyclopaedia is its index. As early as 1614 the bishop of Petina, Antonio Zara, included a type of index in his *Anatomia ingeniorum et scientiarum* ("Anatomy of Talents and Sciences"). A Greek professor at Basel, Johann Jacob Hoffman, added an index to his *Lexicon universale* of 1677; the *Encyclopédie* was completed by a two-volume "Table analytique et raisonnée" for the entire 33 volumes of text, supplements, and plates; and the *Britannica* included individual indexes to the lengthier articles in its 2nd edition (1778–84) and provided its first separate index volume for the 7th edition (1830–42). The nature of good indexing was still far from being fully understood, however, and it was only later in the 19th century that really good encyclopaedia indexes were prepared. In the 20th-century encyclopaedias that provided indexes, the reader was invariably advised to read the guides to their use, because the index had become a sophisticated tool offering a wealth of information in one alphabetical sequence. Breaking with the alphabetical approach to indexing, the *Britannica Electronic Index,* made available in 1992, was an inventory of all index terms of the *Encyclopædia Britannica*; it was to be used topically by the reader. By the 21st century, electronic indexing had grown so sophisticated that it facilitated movement through a database, showed topical relationships, and occasionally even offered users the opportunity to form their own groupings of related articles.

Illustrative material. The use of illustrations in encyclopaedias dates back almost certainly to St. Isidore's time. One of the most beautiful examples of an illustrated encyclopaedia was the abbess Herrad's 12th-century *Hortus deliciarum*. In many earlier encyclopaedias the illustrations were often more decorative than useful, but from the end of the 17th century the better encyclopaedias began to include engraved plates of great accuracy and some of great beauty. The *Encyclopédie* is particularly distinguished for its superb volume of plates—reprinted in the 20th century. In modern times the trend has been toward more lavish illustration of encyclopaedias, including elaborate coloured anatomical plates with superimposed layers and specially inset small coloured halftones, as well as marginal line drawings. With the advent of electronic delivery of databases, intricate animations and audio and video clips became common features of online and disc-based encyclopaedias.

Early illustrated encyclopaedias

The level of writing. The American editor Franklin H. Hooper, undaunted by his own lack of scholarship, took a notable part in ensuring that the articles of the 11th edition of *Encyclopædia Britannica* were kept within the mental range of the average reader. The problem of the encyclopaedist has always been to strike the right mean between too learned and too simplified an approach. The Roman Cassiodorus wrote his encyclopaedia to provide a bridge between his unlettered monks and the scholarly books he had preserved for their use. Hugh of Saint-Victor, the theologian and philosopher, achieved one of the best approaches in his charming *Didascalion* (*c.* 1128), in which he used an elegant and simple style that everyone could appreciate. The abbess Herrad, knowing her audience, described in didactic fashion the history of the world (with emphasis on biblical stories) and its content, with commentaries and beautifully coloured miniatures designed to help and edify the simple nuns in her charge. The master of Dante, Brunetto Latini, wanted to reach the Italian cultured and mercantile classes with his *Li livres dou trésor* ("Treasure Books"; *c.* 1264) and therefore used a concise and accurate style that evoked an immediate and general welcome. Gregor Reisch managed to cover the whole university course of the day in his very pleasing and brief *Margarita philosophica,* which correctly interpreted the taste of the younger generation at the end of the 15th century.

Until the 17th century there had been a great many encyclopaedias written by clerics for clerics, and further examples continued to be published. After that time, more popular works began to be published as well, particularly in France, where such palatable compilations as the Sieur Saunier's *Encyclopédie des beaux esprits* ("Encyclopaedia of Great Minds"; 1657) had an immediate success. The philosopher Pierre Bayle in his *Dictionnaire historique et critique* (1697) introduced the lay reader to the necessity of reading more critically; in this his work constituted a forerunner of the *Encyclopédie,* with its challenges to many undiscriminating assumptions about religion and politics, history and government. On the other hand, the contemporary *Dictionnaire universel* of the Jesuit fathers of Trévoux had a popularity among the orthodox that caused it to run through six editions and then gradually to expand from three to eight volumes between 1704 and 1771.

Encyclopaedias for clerics and lay readers

Supplementary material. The idea of keeping encyclopaedias up-to-date by means of supplements, yearbooks, and so on, dates back more than two centuries. In 1753 a two-volume supplement to the 7th edition of Ephraim Chambers' *Cyclopaedia* was compiled by George Lewis Scott, a tutor to the English royal family. Charles-Joseph Panckoucke, a publisher, issued a four-volume supplement to the *Encyclopédie* (1776–77), in spite of Diderot's refusal to edit it. The *Britannica* included a 200-page appendix in the last volume of the 2nd edition (1784) and issued a two-volume supplement to the 3rd edition (1801; reprinted 1803). *Brockhaus* broke new ground by issuing in monthly parts (1857–64) a yearbook to the 10th edition (1851–55), which, on the commencement of the issue of the 11th edition, changed its name to *Unsere Zeit* ("Our Times") and doubled its frequency (1865–74). In 1907 Larousse began publication of the *Larousse mensuel illustré* ("Monthly Illustrated Larousse"). *The New International Encyclopaedia* issued a yearbook from 1908 (retrospective to 1903), and the *Britannica* issued one yearbook in 1913 and recommenced with the *Britannica Book of the Year* in 1938. The publication of supplements has a much longer history in China, but the system on which the Chinese operated was very different from that of the West (see below). Today yearbooks are a common feature of most general encyclopaedias. In the main, they are more effective in recording the events and discoveries of each year than they are in keeping the main articles up-to-date, but they perform an essential duty in informing their readers of much that is not reported or that is only inadequately reported in the press; at the same time, they provide a more

reasoned assessment and perspective than the daily newspapers and the weekly commentaries can usually achieve.

Some of the leading encyclopaedias offer additional services that are not too widely known. The modern encyclopaedia is a complex work of reference, and the reader needs expert guidance to get the best from its contents. To this end, small subject guides are sometimes issued, which in narrative form outline the whole field and bring each topic into perspective, drawing attention to the appropriate articles that will throw further light on the matter. Another supplementary feature offered by some established encyclopaedias is a research service through which purchasers are permitted to submit a limited number of questions about topics either not dealt with in the set or dealt with inadequately. Such services have been provided in a variety of ways. In some cases, frequently asked questions may be answered with previously prepared reports listed in the publisher's catalog; in others, questions are referred to a special office staff for answers culled from the publisher's own databases; in still others, they may be referred to researchers stationed at selected specialized libraries.

Other supplementary material sometimes issued by encyclopaedias ranges from 10-year illustrated surveys of events to sets of books that have had a major impact on humankind. Although few publishers include dictionaries as an integral part of their encyclopaedia, they frequently supply a well-known, independently compiled work as part of their service. It is an increasingly common custom, however, for a modern encyclopaedia to incorporate an atlas and a gazetteer, often in the last volume.

Problems of encyclopaedias. *Authorship.* In using a reputable encyclopaedia, the reader is inclined to accept the authenticity of any article he or she happens to read. Subconsciously the reader is aware that the highly organized staff of scholars credited for the work must inevitably have ensured the severe scrutiny of all material. Nevertheless, in recent years editors of encyclopaedias have tended more and more to commission signed articles by well-known experts. One of the most famous examples of this was the *Britannica's* commissioning of articles for its 1922 supplement from some of the most famous men and women of the day: "Belgium" by the Belgian historian Henri Pirenne; "Anton Ivanovich Denikin" by the Russian-born jurist and historian Sir Paul Vinogradoff; "Drama" by St. John Ervine, the Irish playwright and novelist; "Czechoslovakia" by the Czech statesman Tomáš Masaryk; and "Russian Army" by Gen. Yuri Danilov. This created a new dimension in encyclopaedias, for it introduced a personal element on a scale previously seen only in the columns of the *Encyclopédie.*

Famous contributors

There is in fact a difference in the treatment of a subject written by a politician such as Masaryk and by an academic historian of distinction. Each writer has something important to offer, and the results will be very different.

Encyclopaedia writing requires teamwork in which each article is edited in relation to others closely connected by subject. If a writer makes a statement that is partly qualified or totally contradicted in another article, the contributions of both writers must be scrutinized by the editorial staff, whose job it is to effect some kind of eventual agreement. Truth can be viewed from many standpoints, and references to any controversy may produce problems demanding all the skill and tact of the editors to resolve, particularly when the reputation of the writer is at stake in a signed article.

Length restrictions. The restrictions imposed by the space available for any particular article are of great consequence. Writing articles for encyclopaedias is an art of its own; within a limited space so much must be compressed—nothing important can be omitted, nothing trivial should be included.

Revision and updating. The revision and updating of an encyclopaedia is one of the greatest challenges to its makers, one to which many ingenious, if admittedly partial, solutions have been found. The problem of keeping an encyclopaedia up-to-date has two facets: the first is to assure that any one printing or edition is as up-to-date as possible at the time of its preparation, and the second is to make it possible for purchasers to maintain the set in an up-to-date condition. One apparent answer to both aspects, the loose-leaf format, has never been a publishing success. Nelson's *Perpetual Loose Leaf Encyclopaedia* (second edition, 1920) was discontinued; the prestigious *Encyclopédie française* (1935–66), however, continues to be available in both loose-leaf and bound volumes.

Louis Moréri set an example in his rapid incorporation of new information in each succeeding issue of his widely used *Grand Dictionnaire historique* ("The Great Historical Dictionary"; 1674). When the German publisher Friedrich Arnold Brockhaus first issued his great encyclopaedia, he was forced by an unexpectedly large public demand to issue edition after edition in quick succession (some of them even overlapped). In all of these he took great pride in providing the latest information, personally supervising much of the revision of individual articles. Moreover, he provided special supplements incorporating these revisions for purchasers of each edition.

In the 18th and 19th centuries, most encyclopaedias that lasted long enough to require revision met the problem by preparing a new edition or by issuing supplements. In the case of *Encyclopædia Britannica,* the first edition (1768–71) was replaced by an essentially new and enlarged second edition in 1777–84; the ninth edition (1875–89), however, remained in print until the preparation of the 11th edition (1910–11), with a 10th edition nominally created by the addition of 11 supplementary volumes in the interim. Among the most serious shortcomings of the new-edition method was the tendency of publishers to dismiss editorial staff after the preparation of a new edition, a practice which meant that skilled editors were dispersed and had to be replaced once the decision to create a new edition had been taken.

Early in the 20th century it became the practice to fill the gaps between new editions with annual summaries called yearbooks. A turning point came when, soon after the publication of its 14th edition in 1929, *Encyclopædia Britannica* announced the introduction of a system of continuous revision that in one form or another is now the practice of most major encyclopaedias in many countries. Under continuous revision programs, some percentage of the articles in a set are updated or improved in other ways on a flexible schedule. Several publishers were able to take advantage of 20th-century printing technologies to reprint their sets on an annual basis and to introduce into each new printing as many revised entries as possible. The system implies the existence of a permanent editorial department able, with the assistance of academic advisers and article authors, to monitor the condition of entries on a constant basis.

Continuous revision

Continuous revision has certain drawbacks. The most serious disadvantage may relate to the rapidity with which articles in a set become noticeably unbalanced in relation to one another. Changes and events requiring revision of articles are more readily apparent in the scientific, technological, biographical, and historical areas, with the result that articles in such fields are revised much more frequently than articles in such fields as the humanities, where important changes do occur, though more subtly.

An equally important disadvantage in continuous revision has to do with the inherent difficulty of revising, on an article-by-article basis, a set of reference books containing many thousands of articles. First, editors are usually unable to revise all the articles that might be affected by a new development. In the case of the assassination of a president, for instance, the editors of the next printing might add the event to the president's biography and even to the history of the country but be unable to acknowledge the event in all the other articles in which the president's name appears. Second, updating a single article is not always as simple as it might at first appear to be. In a biography, for instance, critical events can occur so often that it soon becomes no longer possible simply to add an additional sentence to the end of the piece: the death of the subject of the biography might be the occasion for a reassessment of the person's significance or for the disclosure of long unknown or unpublicized information; in archaeology, a new discovery may be at serious variance with several previously held theories

on which a whole article might well be based. In such instances, revision must go beyond the simple addition of a sentence or the insertion of a word or date and may involve partial or complete rewriting. With the rapid pace of modern research, this can quickly become an ever-present editorial problem of great complexity.

Controversy and bias. Throughout the years most major encyclopaedias have been accused of reflecting bias in one or more of their articles. In the *Encyclopédie* the lack of neutrality was intentional and apparent. Various editions of *Encyclopædia Britannica*, almost from the beginning, were accused of bias as well. The practice of relying on outside specialists for articles, a practice now followed by most serious encyclopaedias, has increased the likelihood that bias will be worked into an article. Many critics have felt that the reader is protected in such cases by the fact that the identity of the contributor is not hidden. It has also been argued that the presence of slanted opinions in an article gave to older encyclopaedias a colour and sense of conviction that is lacking in most modern works. Modern editors of major encyclopaedias, nevertheless, make every effort to eliminate any hint of bias in their sets, but the task is a difficult one. For example, an account of the Korean War would vary according to whether it was written by a North or South Korean, a Chinese, or an American writer.

Similarly, the inclusion of a map showing the frontiers between two or more nations may give rise to vigorous controversy if the nations involved were to dispute any part of the boundaries as shown. The illustration of a painting with an attribution to one artist may draw strong protests from art critics who do not agree with the writer. Controversy today has grown rapidly on many subjects that were not in dispute a few years ago.

The kinds of encyclopaedias

GENERAL ENCYCLOPAEDIAS

It is now possible to see, in the past 2,000 years of encyclopaedia production, the existence of a pattern closely related to the changing social needs of each age. The outstanding circumstances that governed the policy and production of encyclopaedias for the first 15 centuries were that comparatively few people were able to read and, stemming partly from this and partly from the cost of materials and workmanship, that copies of any lengthy work were very expensive. Only when printing was introduced into Europe did the cost of production drop by any large amount; this development in turn helped to stimulate the growth of readership. A notable feature at the time of the early printing press was the sudden growth in the popularity of some of the older encyclopaedias as a result of the tendency to ensure a ready market by printing works of which many manuscript copies were in circulation.

Influence of printing

During the first 16 centuries of their publication the majority of encyclopaedias comprised great anthologies of the most significant writings on as many subjects as possible. The arrangement of these excerpts was constantly varying according to the individual compiler's concept of the hierarchies of human knowledge; some of these classification systems were more suitable than others, but none was completely successful in meeting the tastes of the reading public, because there was no general agreement on the essential order of ideas. Although the compiler exercised considerable latitude in choosing items to include in the encyclopaedia, comment was often restricted to a minimum, so that the reader was free to form an opinion of what was offered. In addition, because the compiler selected material from what had already been written, the reader was referred to the past, and, although he or she could enjoy the heritage of the preceding cultures, the reader was not being put in touch with as much of the contemporary world as might have been desired.

About the 10th or 11th century, a new type of encyclopaedia began to emerge, probably stimulated by the growing number of language dictionaries that, starting well before printing was used, grew ever more numerous once they could be produced. Many early dictionaries were little more than enlarged glossaries, but, from the time of *Suidas* onward, there began to appear a type of dictionary—now called encyclopaedic—that added to the definition and etymology of a word a description of the functions of the thing or idea it named. In some dictionaries, such as those of the Estiennes, a French family of bookdealers and printers, this description might in some cases be of considerable length. Thus the compilers of the new form of encyclopaedia that emerged in the 16th and 17th centuries inevitably thought in terms of arranging their entries in alphabetical order because the dictionaries had already familiarized the reading public with this system.

The last half of the 18th century brought such an upheaval in man's concept of the world that the time was ripe for further experiments in the form of the encyclopaedia. The French encyclopaedists Diderot and d'Alembert and their band of contributors broke no new ground in the physical format and arrangement of the encyclopaedia, but their work inspired the intelligentsia of other nations to produce really good encyclopaedias of their own. It is no coincidence that both the German *Brockhaus* and the Scottish *Britannica* appeared with policies so different from all that had gone before that no publisher of any new encyclopaedia could afford to ignore their new patterns. Their formulas were so good that the modern encyclopaedia is simply a vastly improved elaboration of their method of arrangement and organization. The compilers of both encyclopaedias had taken the best ideas from the anthologies and miscellanies of the early period of encyclopaedia making and from the later stage of encyclopaedic dictionaries. Realizing that the reading public would not tolerate the omission of some subjects and the unequal treatment of others, they prepared works in which at least a few lines were devoted to almost every conceivable topic, and for more important subjects a full account was provided, written by an expert, if possible.

Formulas of *Brockhaus* and *Britannica*

The three periods of the history of encyclopaedias—(1) to 1600, (2) 1601–1799, and (3) 1800 onward—are very unequal. They are, moreover, to a certain extent misleading, for the different forms of the encyclopaedia overlapped at each turning point for some years, and even today there are still some important survivals from the two earlier periods. One can study and compare what each of the three main types of encyclopaedia has had to offer by reading entries on the same subject in the *Encyclopédie française*, *Webster's Third New International Dictionary*, and the *Encyclopædia Britannica*. The *Encyclopédie française* will provide one or more well-written treatises on the subject by writers of note. This is exactly what the encyclopaedias of the earliest period offered; and in both the old and the contemporary encyclopaedia the reader is left free to form an opinion after reading what the experts have to say. *Webster's*, a one-volume work, of course provides much less, but it also gives much more, because it adds definitions and, often, explanatory drawings or diagrams to an admirably concise text that tells the reader much in a very few lines. This is exactly what the encyclopaedic dictionaries of Louis Moréri, Antoine Furetière, and others were offering in the 17th and 18th centuries. The *Britannica*'s contribution is distinct from those of the other two in that it provides a synthesis of what is known on the subject to date and attempts to assess its current position.

The encyclopaedias of the period before 1600 apparently were designed for a small group of people who had much the same educational background as well as similar interests and opportunities to pursue them. In general, they had a common outlook on both religious and secular matters. Moreover, although they were citizens of many different countries, they were united by their knowledge and use of Latin, the international language.

Background of readers before 1600

The Eastern Roman emperor Constantine VII Porphyrogenitus (905–959) tried to plant firmly in the hearts of the most worthy of his contemporaries both knowledge and experience of the past. His were troubled times, and he felt justified in using much of his enforced leisure (he came to the throne in 911 but was not allowed to rule until 945) to provide for the administrators and emissaries of his court the most useful extracts from the writings of a very catholic selection of authors, including the patriarch of Constantinople John of Antioch (Johannes Scholasti-

cus), the Roman historian Appian, the Greek historian Polybius, the Greek philosopher Socrates, the 5th-century Byzantine historian Zosimus, and many others. One of the unexpected by-products of this industry was the preservation of a large number of writings, a service that some of the other medieval encyclopaedias also performed.

An advantage of the encyclopaedists of the first period (*i.e.*, before 1600) was that each of them either knew or could visualize his reading public, a point that encouraged a minimum of commentary and moralizing. In a way, they were performing the duties of a personal librarian in that they drew their readers' attention to innumerable passages that they believed might be useful to them in their work or their private lives. The possibility of achieving even more was fully appreciated: the English scholar Alexander Neckham, in his early 13th-century *De naturis rerum* ("On the Natures of Things"), hoped that by imparting knowledge he might help to lift or lighten man's spirit, and to this end he tried to maintain a simple and admirably clear text. Neckham's near-contemporary Bartholomaeus Anglicus similarly set himself in his *De proprietatibus rerum* ("On the Characteristics of Things") to bring to his readers' attention the nature and properties of the things and ideas on which the early Christian Fathers and the philosophers had expatiated, but he forbore to comment on their writings, leaving his readers to form their own judgments. The anonymous compiler of the *Compendium philosophiae* ("Compendium of Philosophy"; *c.* 1316) believed the knowledge of truth to be the supreme and final perfection of humankind; thus he never moralized on the contents of his encyclopaedia, its cumulative effect thereby being the more impressive.

Encyclopaedias of classical times

Within the early period of the history of encyclopaedias a number of stages can be distinguished that make each group of works significant in any study of the development of scholarship throughout the West. Encyclopaedias of classical times reached their culmination in Pliny's *Historia naturalis*, which was issued in the time of the Roman emperor Titus (AD 39–81). Not one of the encyclopaedias of Pliny or his predecessors paid much attention to religion; if it was discussed, the approach was antiquarian, the gods of the different nations ruled by Rome being named and described in a dispassionate spirit that reflected both the tolerance and the noninvolvement of the Romans in these matters. The emphasis instead was on government, geography, zoology, medicine, history, and practical matters. The theories of the various philosophers were outlined impartially, no indication being given of any personal preference. This objective approach adopted by the Romans in their encyclopaedias was not achieved again until the 19th century.

By the time of the Roman philosopher Boethius and the statesman Cassiodorus (*i.e.*, the 5th and 6th centuries AD), the position concerning objectivity had changed. Like Pliny and the Roman statesman Cato, Cassiodorus had been an administrator; and, while his predecessors had been engaged in interpreting and epitomizing the knowledge of the ancient world for the benefit of their own people, Cassiodorus realized the necessity for providing a new interpretation of this knowledge for the Goths, the new masters of Italy. In the next 700 years the impact of Christianity brought a new phase in Western encyclopaedia making, just as the impact of Islām is clearly visible in the Arabic encyclopaedias of the same period. Although religion is not always given pride of place in the encyclopaedias of those times, it pervades the whole of their contents. Thus Cassiodorus' division of his encyclopaedia into two main sections—divine and human—is made even more interesting by his inclusion of cosmography, the liberal arts, and medicine in the first section. Although the compilers of the encyclopaedias of this period could envisage in theory a perfectly logical arrangement for their encyclopaedias by starting with the creation and working downward to the smallest and least significant of God's creations, in practice they found this very difficult to apply, and the result was often only superficially scientific. Moreover, the inclusion of such topics as astrology and magic was surprisingly prevalent and only began to disappear after the publication of *Liber floridus* ("The Flowering Book"; *c.* 1120), by Lambert, a canon of Saint-Omer, a work that discarded practical matters in favour of metaphysical discussion.

Use of the vernacular

The third stage in the development of encyclopaedias came with the introduction of vernacular editions, such as the *Mappemonde* and *Li livres dou trésor*, and the reflection of the impact of Greek philosophical works (in translation) in the middle of the 13th century. In this era there was an increasing number of lay encyclopaedists—*e.g.*, Latini, Bandini, de la Torre—and the subject coverage changed to give more space and importance to the practical matters that interested the rising mercantile class. At the same time, theology no longer dominated the classification schemes. Humanism reached its full expression in the Spanish philosopher Juan Luis Vives' *De disciplinis* (1531), in which all the compiler's arguments were grounded on nature and made no appeal to religious authority. The printing press had eliminated one of the most vexatious problems: the introduction or perpetuation of textual errors by the manuscript copyists. At the same time, the wider circulation of encyclopaedias through the unrestricted sales of printed copies brought about a situation in which the compilers could no longer envisage their reading public and accordingly adjusted their approach to their largely unknown audience.

ENCYCLOPAEDIC DICTIONARIES

The period spanning the 17th and 18th centuries is characterized by the flourishing of the encyclopaedic dictionaries that were pioneered by the Estienne family in France in the 16th century. During these two centuries this form of encyclopaedia reflected two different policies. There was the encyclopaedia, such as those of the Germans Johann Theodor Jablonski and Johann Heinrich Zedler, that paid particular attention to the fields of history and biography. There was also a new form of encyclopaedia—if the exception of the 12th-century *De diversis artibus* be set aside—that devoted itself to the arts and sciences. The first type can therefore be said to be retrospective in approach, while the arts and sciences encyclopaedia was clearly identifiable with contemporary matters.

None of these divisions is actually clear-cut, for many traditional encyclopaedias continued to be compiled throughout the period, and not all the historical-biographical encyclopaedias ignored the arts and sciences or contemporary people and events. Nevertheless, the issue of Antoine Furetière's encyclopaedia and the immediate follow-up by *Le Dictionnaire des arts et des sciences* (1694) by the writer Thomas Corneille (the younger brother of the playwright Pierre Corneille) were sufficient to indicate the growing public interest in a more modern form of encyclopaedia. This indication was confirmed by the successful publication of John Harris' *Lexicon Technicum* (1704), which the author described as "an universal English dictionary of arts and sciences: explaining not only the terms of art, but the arts themselves." It is significant that Harris omitted such subjects as theology, biography, and geography. The Englishman Ephraim Chambers went even further in describing his internationally influential *Cyclopaedia* (1728) as

> an universal dictionary of arts and sciences; containing an explication of the terms, and an account of the things signified thereby, in the several arts, both liberal and mechanical, and the several sciences, human and divine, compiled from the best authors.

Ideal contents as viewed in the 18th century

No century has seen more public discussion of the nature of the encyclopaedia than the 18th; at the same time, there was much uncertainty concerning its ideal contents. The fine Italian encyclopaedia of Gianfrancesco Pivati (the secretary of the Academy of Sciences at Venice), the *Nuovo dizionario scientifico e curioso, sacroprofano* ("New Scientific and Curious, Sacred-Profane Dictionary"; 1746–51), avoided the subject of history, whereas the German writer Philipp Balthasar Sinold von Schütz's *Reales Staats- und Zeitungs-Lexicon* ("Lexicon of Government and News"; 1704) concentrated on geography, theology, politics, and contemporary history and had to be supplemented by the German economist Paul Jacob Marperger's *Curieuses Natur-, Kunst-, Berg-, Gewerk- und Handlungslexikon*

(1712; "Curious Natural, Artistic, Mining, Craft, and Commercial Encyclopaedia"), which covered the sciences, art, and commerce.

The introduction of the arts and sciences type of encyclopaedia inevitably hastened the use of specialist contributors, for it widened the total subject field considerably. "Hübner" (as Sinold von Schütz's encyclopaedia was known from the writer of the preface) employed many contributors, and it is known from the draft prospectus of the British writer Oliver Goldsmith that an encyclopaedia he projected was to have included comprehensive specialist articles by the lexicographer Samuel Johnson, the statesman Edmund Burke, the portrait painter Sir Joshua Reynolds, the historian Edward Gibbon, the economist Adam Smith, and others. The remarkable progress made in this period can easily be judged when one compares the encyclopaedia *Lucubrationes* (1541), in which the author, Joachim Sterck van Ringelbergh, found it necessary to include a "miscellaneous" section (which he amusingly dubbed "Chaos"), with the approach of Johann Georg Krünitz, a German physician and philosopher, in his highly organized, modern *Oekonomisch-technologische Encyklopädie* ("Economic-Technological Encyclopaedia"; 1773–1858) with its 242 volumes.

THE MODERN ENCYCLOPAEDIA

The period of the encyclopaedic dictionary was brilliant, but it gradually became apparent that, in abandoning the systematic encyclopaedia of the earlier period in favour of the quick reference dictionary form, quite as much had been lost as had been gained. The comparatively brief entries in the encyclopaedic dictionary had, by accident of the alphabet, fragmented knowledge to such an extent that users received only a disjointed knowledge of the things in which they were interested. Nor had the willful and extremely individualistic effort of the French encyclopaedists Diderot and d'Alembert done more than confuse the issue, for they had bent the principles of encyclopaedia making to their own purposes. An initial solution to the problem was found by Andrew Bell (1726–1809), Colin Macfarquhar (*c.* 1745–93), and William Smellie (1740–95), three Scotsmen who were responsible for the first edition (1768–71) of *Encyclopædia Britannica*. Aware of the shortcomings of the *Encyclopédie*, they devised a new plan. Their encyclopaedia was to include about 45 principal subjects (distinguished by titles printed across the whole page), supported by another 30 lengthy articles, the whole being contained within one alphabetical sequence interspersed with numerous brief entries enhanced by references, where appropriate, to the principal subjects. Some of the principal articles, notably those on medical subjects, extended to more than 100 pages each. The three collaborators had thus incorporated the comprehensive treatment of important subjects accorded by the earliest form of encyclopaedias and had supplemented this with the attraction of the brief informative notices of minor topics that had been the chief feature of the encyclopaedic dictionary. The key to their success was, however, their retention of the single alphabetical sequence.

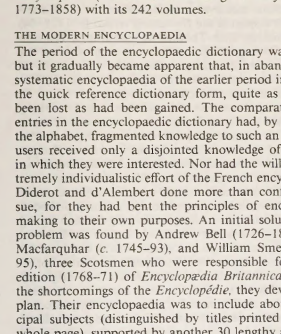
Plan of the first *Encyclopædia Britannica*

Meanwhile, Renatus Gotthelf Löbel was planning to compile an encyclopaedia that could supersede "Hübner." It was Sinold von Schütz who, in the fourth edition of "Hübner," had introduced the word *Conversations-Lexikon* into the title, and it was Löbel who decided to give it pride of place in his new encyclopaedia. The *Konversationslexikon* was designed to provide the rapidly growing German bourgeoisie with the background knowledge considered essential for entry into the polite society of the day. When Brockhaus took over Löbel's bankrupt and incomplete encyclopaedia, he saw the value and appeal of this evocative word and retained it (in various spellings) for many years afterward. Löbel's and Brockhaus' solution to the problem of the form of the modern encyclopaedia was not the same as the *Britannica*'s; it is interesting to note that, whereas the *Britannica* model has widely prevailed throughout the English-speaking world, *Brockhaus* has been the model for most of the encyclopaedias prepared in countries in which English is not widely spoken.

Format of the *Konversations-lexikon*

Brockhaus, throughout its existence, has faithfully followed a system in which the whole of knowledge has been categorized into very specific topics. These topics are arranged alphabetically, and, under each heading, condensed entries convey the essential information. By ingenious cross-references, entries are linked with other entries under which further information can be found, thus avoiding the inclusion of an index. There is no difficulty in distinguishing encyclopaedias of the *Konversationslexikon* form from encyclopaedic dictionaries. The former are usually of considerable size (*Der grosse Brockhaus*, 1928–35, included 200,000 articles by over 1,000 authors) and possess elaborate cross-reference schemes. Moreover, whenever a really important subject occurs, considerable space is allowed, though the same principle of concentrated text is followed.

Although the *Britannica* and *Brockhaus* examples eventually became the models for 19th- and 20th-century encyclopaedias, there have been many survivals from the previous periods. Ersch and Gruber's enormous *Allgemeine Encyclopädie* ("General Encyclopaedia"; 1818–89) has been cited as a true example of the medieval "summa"—it is famed for including the longest article in any encyclopaedia, that on Greece, which fills 3,668 pages in volumes 80–87. The *Encyclopédie française* is an even later example of this form, and, as Samuel Taylor Coleridge planned it, the *Encyclopaedia Metropolitana* could have proved the supreme example of this type of treatment. Meanwhile, the encyclopaedic dictionary has never died, and, at the very time when *Brockhaus* and the *Britannica* were building their markets, Noah Webster was developing his dictionary's reputation for reliability.


EB Inc

Encyclopædia Britannica;

OR, A

DICTIONARY

OF

ARTS and SCIENCES,

COMPILED UPON A NEW PLAN.

IN WHICH

The different SCIENCES and ARTS are digested into distinct Treatises or Systems;

AND

The various TECHNICAL TERMS, &c. are explained as they occur in the order of the Alphabet.

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By a SOCIETY of GENTLEMEN in SCOTLAND.

IN THREE VOLUMES.

VOL. I.

EDINBURGH:

Printed for A. BELL and C. MACFARQUHAR,

And fold by GEORGE MACFARQUHAR, at his Printing-office, Nicolfon-ftreet.

M,DCC,LXVIII.

Title page of volume 1 of the first edition of *Encyclopaedia Britannica*, published in Edinburgh, 1768–71.

CHILDREN'S ENCYCLOPAEDIAS

Before the 19th century, only Johann Wagenseil (1633–1705) had produced an encyclopaedia for children—the *Pera Librorum Juvenilium* ("Collection of Juvenile Books"; 1695). Larousse issued an interesting *Petite Encyclopédie du jeune âge* ("Small Children's Encyclopaedia") in 1853, but the next, *Encyclopédie Larousse des enfants* ("Larousse Encyclopaedia for Children"), did not appear until 1957. The first of the modern children's encyclopaedias was, however, a long-standing favourite. Prepared by the English writer and editor Arthur Mee (1875–1943), it was called *The Children's Encyclopaedia* (1910) in Great Britain and *The Book of Knowledge* (1912) in the United States. The contents comprised vividly written and profusely illustrated articles: because the system of article arrangement was obscure, much of the success of the work as a reference tool resulted from its splendidly contrived index, which remains a model of its kind. Arthur Mee

later produced a completely pictorial encyclopaedia, *I See All* (1928–30), that comprised thousands of small illustrations, each accompanied by only a few words of text. Librarians still treasure it for its reference value, even if it is no longer used by children. In 1917–18 a completely new children's encyclopaedia was published, *The World Book Encyclopedia,* which the title page described as "organized knowledge in story and picture." A success from the start, it issued enlarged editions in quick succession. In 1925 a volume devoted to reading courses and study units was added. Annual supplements also were provided from 1922 onward. In 1961 a Braille edition in 145 volumes was issued; most of the illustrations were eliminated in this, but many of the diagrams and graphs were retained. In 1964 a separate 30-volume set in a special large type was published for the use of the partially blind.

World War I put a halt to the idea of issuing a *Britannica Junior,* and the first edition of such a work was not published until 1934. It was based on *Weedon's Modern Encyclopedia,* whose copyright had been bought by Britannica. Renamed *Britannica Junior Encyclopædia* in 1963 (and revised until 1983), it was specifically designed for children in elementary-school grades. One of its features was its ready-reference index volume, which combined short fact entries with indexing to longer general articles. In 1960 a British *Children's Britannica* was issued in London. Prepared under the direction of John Armitage, London editor of *Encyclopædia Britannica,* its contents were determined largely by material covered in the so-called 11-plus standardized tests given in Britain.

In 1970 a new encyclopaedia, called *The Young Children's Encyclopedia,* was issued by Encyclopædia Britannica, Inc. Prepared specifically for children just learning to read and not yet in elementary school, it consisted of 16 volumes, in which all the illustrations were in colour and the accompanying informative text brief. Since its original appearance, the set has been translated into several languages, including Japanese and Korean.

Compton's Encyclopedia

In 1894 Frank E. Compton sold a U.S. school encyclopaedia, the *Students Cyclopedia,* from door to door to pay his way through college. This later became the *New Students Reference Work,* which Compton finally bought. While continuing to publish this, Compton designed a completely new and, for those times, revolutionary work, which first appeared in 1922 as *Compton's Pictured Encyclopedia.* In due course, the system of continuous revision was introduced, close cooperation with educational and library advisers was fostered, and contributions from well-known authors were encouraged. In 1971 *Compton's,* by then published by Encyclopædia Britannica, Inc., introduced *Compton's Young Children's Precyclopedia* (renamed *Compton's Precyclopedia* in 1973), based on *The Young Children's Encyclopedia* described above. In 1989 Encyclopædia Britannica, Inc., introduced *Compton's MultiMedia Encyclopedia*, the first multimedia CD-ROM encyclopaedia; it contained all the information of the printed set as well as sound and animation. Britannica sold *Compton's* in 1993 but bought it back in less than a decade.

Unlike *World Book, Compton's,* and the *Britannica Junior Encyclopædia,* the *Oxford Junior Encyclopaedia* (intended for children of age 11 upward) was systematically arranged. Each of the 12 text volumes was devoted to a broad subject field: humankind, natural history, the universe, communications, great lives, farming and fisheries, industry and commerce, engineering, recreation, law and society, home and health, and the arts. The 13th volume was an index with ready-reference material. The contents of each volume were arranged alphabetically (with cross-references), and there were many illustrations.

SPECIALIZED ENCYCLOPAEDIAS

Special interests. Most encyclopaedias have been compiled from a purely scholarly point of view and have had no particular ax to grind, though nearly all have been inhibited to a certain extent by the interests and policies of the milieu in which they appeared. There are, however, several encyclopaedias that have been planned deliberately for a special purpose. One that is unique and continues to be of the greatest value to historians is the work of the 16th-century Spanish Franciscan Fray Bernardino de Sahagún, who spent much of his life in missionary work in Mexico. Sahagún was ordered to write in Nahuatl the information needed by his colleagues for the conversion of the Indians. The result, the *Historia general de las cosas de Nueva España* ("General History of the Matters of New Spain"), was a magnificent record of the Aztec culture as recounted by the Indians of south-central Mexico. The arrangement of this work, written in pictorial language as well as in Spanish, followed the familiar medieval pattern and resembled most closely that of Bartholomaeus Anglicus (Sahagún may have been familiar with a recent translation of Bartholomaeus' encyclopaedia).

Many of both the Arabic and Chinese classical encyclopaedias were compiled with the object of helping civil service candidates in their studies and of providing administrators with the cultural background needed for their work. Their interest to historians of the two cultures can well be understood, for their arrangement and contents throw useful light on the concepts of administration and justice (to name only two aspects) in the Chinese and Islāmic worlds during the 7th to 15th centuries.

Of the Western medieval encyclopaedias, the most interesting in this respect is the *De naturis rerum* (*c.* 1228–44) of the Dominican friar Thomas de Cantimpré. His aim was that of St. Augustine: to unite in a single volume the whole of human knowledge concerning the nature of things, particularly the nature of animals, with a view toward using it as an introduction to theology.

Religion and politics were the main motives for writing encyclopaedias with a special purpose. Louis Moréri made no secret of his intention to produce an encyclopaedia that would defend the teaching and policies of the Roman Catholic Church. Antoine Furetière and Pierre Bayle, on the other hand, represented the philosophers, and their anticlerical bias was more in tune with the skeptical minds of the age. Nevertheless, there was still a strong orthodox following in France, as the long-continuing demand for the *Dictionnaire universel* of the Jesuit fathers of Trévoux demonstrated, and this encyclopaedia was as firmly in defense of Catholicism as the *Encyclopédie* was critical of it.

Diderot and d'Alembert's encyclopaedia had originally been intended by its publisher to be no more than an adaptation of Ephraim Chambers' *Cyclopaedia.* The outcome was a giant reference work that criticized the government, satirized the Calvinist clergy of Geneva, championed the Age of Reason, and supported an atheistic materialism. To the more rigid members of the French Establishment, the encyclopaedia was a monster. The more worldly, however, had no objection to a work whose succeeding volumes were each an audacious source of scandal.

Even the French encyclopaedist Pierre-Athanase Larousse was not impartial. His finest encyclopaedia, the *Grand Dictionnaire universel du XIXe siècle* ("Great Universal Dictionary of the 19th Century"; 1865–90), one of the most influential of the century, was deliberately anticlerical in policy. And Herder, in the heart of Catholic Germany, produced a counterweight to the Protestant *Brockhaus* in his *Konversations-Lexikon* (1853–57), which adopted a distinctive Roman Catholic viewpoint. This excellent encyclopaedia was early recognized for its general impartiality, scholarship, and accuracy. In the long run, both "Herder" and *Brockhaus* gradually eliminated their sectarian inclinations.

Historical development of topical works. The alternative title of the 12th-century *Speculum universale* ("Universal Mirror") of a French preacher, Raoul Ardent (a follower of Gilbert de La Porrée, a French theologian), was the *Summa de vitiis et virtutibus* ("Summa [Exposition] of Faults and Virtues"). Raoul's intent was to provide a modern authoritative account of the Christian attitude to the world. His plan was different from that of other encyclopaedists, for he limited his work to the discussion (in this order) of theology, Christ and redemption, the practical and ascetic life, thought, prayer, ethics, the four cardinal virtues, human conduct, and the four senses. This work could, in fact, be termed the first of the specialized, or topical, encyclopaedias.

Apart from isolated examples, and the technical encyclopaedia of Roger of Helmarshausen, the specialized encyclopaedia did not really make an appearance until the 18th century. The stimulus was probably provided by the increasing number of encyclopaedias that included the arts and sciences to such a point that some of them included little else. In any classified encyclopaedia the individual classes do, of course, constitute a kind of specialized encyclopaedia, but such a work is not sufficiently self-contained to stand on its own. As the boundaries of knowledge contained in encyclopaedias expanded, there were at least some attempts to produce specialized works of this kind.

The emergence of specialized encyclopaedias

Biography. The first real effort toward a specialized encyclopaedia was made in the mid-18th century, and the subject field that it treated was biography. The *Allgemeines Gelehrten-Lexicon* ("General Scholarly Lexicon"; 1750–51) was compiled by Christian Gottlieb Jöcher, a German biographer, and issued by Gleditsch, the publisher of both "Hübner" and Marperger and the opponent of Zedler's encyclopaedia. Jöcher's work was continued by the German philologist Johann Cristoph Adelung and others and is still of value today. The field of international biography is not a simple one to tackle, and there were only two further efforts of note: J.C.F. Hoefer (1811–78) compiled the *Nouvelle Biographie générale* ("New General Biography"; 1852–66), and J.F. Michaud (1767–1839) was responsible for the *Biographie universelle*. These two great works were to a certain extent competitive, which helped to improve their coverage and content; they are still heavily used in research libraries. After their publication, the task of recording biographical information on a universal scale reverted to the general encyclopaedias.

Chemistry, music, and philosophy. Developments in the field of specialized encyclopaedias correspond closely to other developments in the world of scholarship. It is, for example, no accident that so much attention should be paid to the subject of chemistry at a time when L.F.F. von Crell was issuing his series of abstract journals on chemistry. The English scientist and inventor William Nicholson (1753–1815) was first in the field with his *Dictionary of Chemistry* (1795), published by Sir Richard Phillips (who later issued C.T. Watkin's *Portable Cyclopaedia*). On this was based Andrew Ure's *Dictionary of Chemistry*, which was for a long time the standard reference work on the subject in Great Britain. In 1807 the German chemist Martin Heinrich Klaproth issued his *Chemisches Wörterbuch* ("Chemical Dictionary"), but a more important event was the publication of the *Handbuch der theoretischen Chemie* ("Handbook of Theoretical Chemistry"; 1817–19) by the German scientist Leopold Gmelin, a work of such excellence that it still appears in new editions from the Gmelin-Institut. Heinrich Rose, a German chemist, issued his *Ausführliches Handbuch der analytischen Chemie* ("Complete Handbook of Analytic Chemistry") in 1851, and the first edition of the famous Liebig, Poggendorff, and Wöhler's *Handwörterbuch der reinen und angewandten Chemie* ("Handbook of Pure and Applied Chemistry") was issued in 1837; its second edition (1856–65) was expanded to nine volumes. This work was continued by Hermann Fehling's *Neues Handwörterbuch der Chemie* ("New Pocket Dictionary of Chemistry"; 1871–1930). The French counterpart, C.A. Wurtz's *Dictionnaire de chimie pure et appliquée* ("Dictionary of Pure and Applied Chemistry"; 1869–1908), became the standard work of its day. The Russian-born chemist Friedrich Konrad Beilstein first issued his *Handbuch der organischen Chemie* ("Handbook of Organic Chemistry") in Hamburg, Ger., in 1880–83; it is the most extensive work of its kind today. The French chemist Edmond Frémy's *Encyclopédie chimique* ("Chemical Encyclopaedia") appeared in 1882–99, and *A Dictionary of Applied Chemistry*, edited by Sir Thomas Edward Thorpe, the English chemist, was first issued in 1890–93. Standard works of the 20th century included Fritz Ullmann's *Enzyklopädie der technischen Chemie* ("Encyclopaedia of Applied Chemistry"; 1914–23), Victor Grignard's *Traité de chimie organique* ("Treatise on Organic Chemistry"; 1935), *Elsevier's Encyclopaedia of Organic Chemistry* (1940), the *Encyclopedia of Chemical Technology* (1947–56; known by the names of its principal editors as "Kirk-Othmer"), Waldemar Koglin's *Kurzes Handbuch der Chemie* ("Short Handbook of Chemistry"; 1951), and the indispensable *CRC Handbook of Chemistry and Physics*, which in 2003 had run to 84 editions.

Encyclopaedias of chemistry

The impressive run of encyclopaedias and handbooks of chemistry over so long a period is paralleled only in the field of music, in which the *Musikalisches Lexikon* ("Musical Lexicon"; 1732) of the German composer and music lexicographer Johann Gottfried Walther began the trend and was supplemented by the very successful *Historisch-biographisches Lexicon der Tonkünstler* ("Historical and Biographical Lexicon of Musicians"; 1790–92) of the German organist and music historian Ernst Ludwig Gerber. The *Biographie universelle des musiciens et bibliographie générale de la musique* ("Universal Biography of Musicians and General Bibliography of Music"; 1835–44) was compiled by the director of the Brussels Conservatoire, the Belgian composer François-Joseph Fétis, almost coinciding with the equally voluminous *Encyklopädie der gesammten musikalischen Wissenschaften* ("Encyclopaedia of Collected Musical Knowledge") of Gustav Schilling, a German lexicographer and historian of music. Hermann Mendel, a pupil of Felix Mendelssohn, founded the *Musikalisches Conversations-Lexikon* (1870), which was completed by August Reissmann, who also edited the musicologist and composer Auguste Gathy's *Musikalisches Conversations-lexikon* (1871). The great *Encyclopédie de la musique et dictionnaire du Conservatoire* (1913–31) was begun by the French writer on music Albert Lavignac and continued by Lionel de La Laurencie, but the third part, a dictionary of names and subjects covered in the preceding parts, was never issued. Walter Willson Cobbett compiled the *Cyclopedic Survey of Chamber Music* (1929–30), and the English writer on music Sir George Grove first issued his *Dictionary of Music and Musicians* in 1879–89; it went through five editions until a new work, *The New Grove Dictionary of Music and Musicians*, appeared in 20 volumes in 1980. A 29-volume second edition of the *New Grove* appeared in 2001; this edition is also available online, as are Grove's dictionaries of jazz and opera.

Encyclopaedias of music

The publication of the German philosopher G.W.F. Hegel's *Encyklopädie der philosophischen Wissenschaften* ("Encyclopaedia of Philosophical Knowledge"; 1817) was of more than subject importance in that it was a compendium of the author's philosophical system in three parts: Logic, Nature, Mind. It influenced many editors of general encyclopaedias during the rest of the century. The standard work in this field has for many years been the *Dictionary of Philosophy and Psychology* edited by the American psychologist James Mark Baldwin, though the publication of *The Encyclopedia of Philosophy* (1967) provided a substantial work more in line with modern tastes. Other works in this area include the Centro di Studi Filosofici di Gallarate's *Enciclopedia filosofica* (1957), the French philosopher André Lalande's *Vocabulaire technique et critique de la philosophie* ("Technical and Critical Vocabulary of Philosophy"; first issued 1902–12), and the Austrian writer Rudolph Eisler's *Wörterbuch der philosophischen Begriffe* ("Dictionary of Philosophical Concepts"). The *Routledge Encyclopedia of Philosophy* (1998) was the first multivolume encyclopaedia published in the discipline in more than 30 years, and it is also available online.

Encyclopaedias of philosophy

Other topics. The Architectural Publication Society began issuing its *Dictionary of Architecture* as early as 1852, but it took 40 years to complete. A more modern work is *Wasmuths Lexikon der Baukunst* ("Wasmuth's Lexicon of Architecture"; 1929–37). Further material is included in the *Encyclopedia of World Art* (1959–68), the *Reallexikon für Antike und Christentum* ("Encyclopaedia for Antiquity and Christianity"; begun 1950), the *Enciclopedia dell'arte antica, classica e orientale* ("Encyclopaedia of Ancient, Classical, and Oriental Art"; 1958–66), and Grove's *Dictionary of Art* (1996; also online).

The words "Pauly-Wissowa" are very familiar to a great number of people. August von Pauly (1796–1845), the German classical philologist, began issuing his *Real-Encyclopädie der classischen Altertumswissenschaft*

("Encyclopaedia of Classical Antiquities") in 1837. The new edition was begun by another German classical philologist, Georg Wissowa, in 1893. This enormous work on classical studies has no equal in any part of the world, though it can be supplemented in some areas by the encyclopaedic series *Handbuch der Altertumswissenschaft* ("Handbook of Antiquities") begun in 1887.

The Swiss theologian J.J. Herzog (1805–82) gave religion its first great encyclopaedia with his *Real-Encyklopädie für protestantische Theologie und Kirche* ("Encyclopaedia of the Protestant Theology and Church"; 1854–68). Philip Schaff (1819–93), a Swiss-born American church historian, prepared the abridged English edition (1882–84) from which *The New Schaff-Herzog Encyclopedia of Religious Knowledge* stems. James Hastings, a Scottish clergyman, was responsible for no fewer than four encyclopaedic works in this field: *A Dictionary of the Bible* (1898–1904); *A Dictionary of Christ and the Gospels* (1906–08); *Encyclopaedia of Religion and Ethics* (1908–26), still of great importance; and *Dictionary of the Apostolic Church* (1915–18). An even more significant series is the *Encyclopédie des sciences ecclésiastiques* ("Encyclopaedia of the Ecclesiastical Sciences"), which will take many decades to complete. It comprises the *Dictionnaire de la Bible* (1907–12 and ongoing supplements), *Dictionnaire de théologie catholique* (1909–50), *Dictionnaire d'archéologie chrétienne et de liturgie* (1928–53), *Dictionnaire d'histoire et de géographie ecclésiastiques* (begun 1912), and *Dictionnaire de droit canonique* ("Dictionary of Canon Law"; 1935–65). Other important works are *The Catholic Encyclopedia* (1907–18), which has not been completely superseded by the *New Catholic Encyclopedia* (1967); the finely illustrated *Enciclopedia cattolica* (1948–54); *Die Religion in Geschichte und Gegenwart* ("Religion in the Past and Present"; 1909–13); and the *Lexikon für Theologie und Kirche* ("Lexicon of Theology and the Church"; 1930–38). Other significant encyclopaedias of religion include *The Encyclopaedia of Islam* (new ed., begun 1960); the *Encyclopaedia Judaica* (1972); and *The Encyclopedia of Religion* (1987), edited by Mircea Eliade.

Almanacs and handbooks of social and political science

It was not until the 1860s that three of the most useful handbooks now in daily use began to appear. *The Statesman's Year-Book*, important for its statistical and political information, began publication in 1864. In 1868 the English publisher Joseph Whitaker first issued his *Whitaker's Almanack*, and the *World Almanack* started in the same year. The *Chicago Daily News Almanac* appeared from 1885 to 1946, and the *Information Please Almanac* began in 1947. Herder's *Staatslexikon* ("Lexicon of Political Science") was first published in 1889–97; this compendium was soon followed by the *Dictionary of Political Economy* (1894) by the English banker and economist Sir Robert Palgrave. In 1930–35 the *Encyclopaedia of the Social Sciences* was published; an immediate success, it is often referred to as "Seligman" after the name of its chief editor. The new *International Encyclopedia of the Social Sciences* (1968) did not supersede it in every respect. In a similar fashion, the *Handwörterbuch der Sozialwissenschaften* ("Pocket Dictionary of the Social Sciences"; 1952–68) supplemented rather than superseded the standard *Handwörterbuch der Staatswissenschaften* ("Pocket Dictionary of Political Science"; 4th ed., 1923–39). By the start of the 21st century, many world almanacs were published annually.

In the field of literature, if Isaac Disraeli's *Curiosities of Literature* (1791) is ruled out, the first important handbook is the *Dictionary of Phrase and Fable* (1870) by the English clergyman and schoolmaster Ebenezer Cobham Brewer (1810–97), supplemented with Brewer's *Reader's Handbook* (1879). Other important works include the *Dizionario letterario Bompiani degli autori* ("Bompiani's Literary Dictionary of Authors"; 1956–57), the *Dizionario letterario Bompiani delle opere* ("Bompiani's Literary Dictionary of Works"; 1947–50), *Cassell's Encyclopaedia of Literature* (1953), and the Oxford "companions" to various world literatures.

In the last quarter of the 19th century, three major specialized encyclopaedias were issued: *Dictionnaire de botanique* ("Dictionary of Botany"; 1876–92) of the French naturalist and physician Henri Baillon, the *Lexikon der gesamten Technik* ("Lexicon of Collected Technology"; 1894–99) of the German engineer Otto Lueger, and the Berlin Academy's *Enzyklopädie der mathematische Wissenschaften* ("Encyclopaedia of Mathematical Sciences"; 1898–1935). The last was shortly followed by the important but incomplete *Encyclopédie des sciences mathématiques pures et appliquées* ("Encyclopaedia of Theoretical and Applied Mathematical Sciences"; 1904–14).

Physics never received the degree of attention that the encyclopaedists accorded to chemistry and chemical engineering. The standard *Dictionary of Applied Physics* of the English physicist Sir Richard Glazebrook was first issued 1922–23. The *Handbuch der Physik* ("Handbook of Physics") was issued from 1926 to 1929; the second edition (1955–88) is often referred to by the name of its editor, Siegfried Flügge. Another work was the *Encyclopaedic Dictionary of Physics* (1961–64; and four supplements, 1966–75), edited by James Thewlis.

In medicine the pioneer *British Encyclopaedia of Medical Practice* (1936–39) was followed by *The Encyclopaedia of General Practice* (1963).

Other important encyclopaedias and handbooks include *The Encyclopedia of Photography* (1949); the superbly illustrated and well-documented *Enciclopedia dello spettacolo* ("Encyclopaedia of the Stage"; 1954–62), which includes all forms of staged entertainment; the *Dictionnaire du cinéma et de la télévision* ("Dictionary of the Cinema and Television"; 1965–71); the *McGraw-Hill Encyclopedia of Science and Technology* (1960; 9th ed., 2002); and the *Encyclopedia of Library and Information Science* (2nd edition, 2003).

Encyclopaedias of countries and regions

A special kind of encyclopaedia dealing with a single country or region began to appear in the late 19th century. Sometimes it is possible to distinguish, by a subtle form of titling, those national encyclopaedias that deal with the world scene from those that concentrate chiefly on their own country. Thus the "Ruritanian Encyclopaedia" can usually be taken to be a work produced in Ruritania that takes a world view, while the "Encyclopaedia of Ruritania" probably deals mainly with Ruritania and Ruritanian matters of interest.

The encyclopaedias of geography are of particular use in this field because they cover in detail many islands, small cities, and other features that are dealt with in only the briefest fashion elsewhere. Of the modern geographic encyclopaedias the following were noteworthy in the 20th century: *Westermanns Lexikon der Geographie* (1968–72); *Meyers Kontinente und Meere* ("Meyer's Continents and Seas"; 1968–73); the Russian *Kratkaya geograficheskaya entsiklopedya* ("Short Geographic Encyclopaedia"; 1960–66); and the *Länderlexikon* ("Geographic Dictionary"; 1953–60). The main 20th-century encyclopaedias dealing with specific continents, regions, and countries were:

Africa: *Encyclopaedia of Southern Africa* (1961); *Deutsches Kolonial-Lexikon* (1920); *Encyclopédie coloniale et maritime* (1942–51); *Grande encyclopédie de la Belgique et du Congo* (1938–52).

Australasia: *The Australian Encyclopaedia* (1958); *Encyclopaedia of Australia* (1968); *The Modern Encyclopaedia of Australia and New Zealand* (1964); *An Encyclopaedia of New Zealand* (1966).

The Americas: *Diccionario enciclopédico de las Américas* (1947); *Verbo: enciclopédia luso-brasileira de cultura* (1963–76 and ongoing supplements); *Diccionario enciclopédico del Perú* (1967); *Enciclopedia Yucatanense* (1944–47); *Enciclopedia de México* (1966–77; 2nd ed. rev., 1993); *Diccionario geográfico, estadístico, histórico, de la isla de Cuba* (1863–66); *Gran enciclopedia argentina* (1956–64); *Encyclopedie van de Nederlandse Antillen* (1969); *Encyclopaedie van Nederlandsch West-Indië* (1914–17); *Enciclopédia larense* (1941); *Encyclopedia Canadiana* (1957–58).

Europe: *Flandria nostra* (1957–60); *Magyar életrajzi lexikon* (1967–69); *Encyclopaedia of Ireland* (1968); *Latvijas PSR mazā enciklopēdija* (1967–72); *Latvju enciklo-*

pėdija (1950–55); *Mažoji lietuviškoji tarybinė enciklopedija* (1966); *Norge* (1963); *Enciclopedia românieі* (1938–43); *Encyclopédie polonaise* (1916–20); *Sverige: land och folk* (1966); *Ukraine: A Concise Encyclopaedia* (1963–71); *Narodna enciklopedija srpsko-hrvatsko-slovenačka* (1925–29).

Middle East: *Eretz-Yisra'el: entziqlopedia ṭopografit-historit* (1946–55).

ELECTRONIC ENCYCLOPAEDIAS

Given the rapid pace of technological advancement in the contemporary world, it was to be expected that encyclopaedia publishers would seek ways to exploit new technologies in the field of information storage, retrieval, and distribution. During the 1960s and '70s these new technologies revolutionized the manner in which article text was generated, modified as needed, and composed and output for printing. The computer terminal, typically linked to a large mainframe computer where the encyclopaedia's contents were stored as an electronic database on magnetic tape or disc, became the key to editorial production. By the 1980s and '90s the phenomenal growth of telecommunications networks and personal computer systems presented a new possibility to the publishing industry—the delivery of encyclopaedic databases through a medium other than the printed page. Many general and specialized encyclopaedias now publish electronic versions of their databases—on CD-ROM (compact disc read-only memory) and DVD (digital videodisc) products and as online services. As computer technology has developed, the electronic encyclopaedia has become less a version of the print set and more a product in its own right, presenting a database in the manner best suited to the electronic medium.

One advantage of the electronic medium is the huge storage capacity that it offers at very low cost. Freed from manufacturing expenses, electronic encyclopaedias are able to expand far beyond their print versions. Electronic presentation also makes articles more readily accessible: in addition to the alphabetical indexes compiled for the print sets, many electronic encyclopaedias feature high-speed search software that can retrieve an exhaustive set of files in response to specific queries.

The most obvious advantage of electronic encyclopaedias is in their "multimedia" capabilities, with animated graphics, recorded sound, and video recordings supplementing the text, photographs, and line drawings inherited from the print medium. With the development of more sophisticated data-processing applications, there arises the potential for truly "interactive" encyclopaedias, which would allow readers to retrieve, manipulate, and classify information according to their own designs.

CD-ROM encyclopaedias. The electronic medium was developed most quickly and visibly on CD-ROM by smaller encyclopaedias or those intended for younger readers. In 1985 Grolier, Inc., issued its *Academic American Encyclopedia* on CD-ROM. This text-only version received still illustrations in 1990, and in 1992, with the addition of audio and video, it became the *New Grolier Multimedia Encyclopedia*. Multimedia enhancement had been introduced in 1989 by *Compton's MultiMedia Encyclopedia*, then owned by Encyclopædia Britannica, Inc. Four years later the Microsoft Corporation released *Microsoft Encarta Multimedia Encyclopedia*, which enhanced the text of *Funk & Wagnall's New Encyclopedia* with extensive graphics, audio, and video.

Larger encyclopaedias initially stressed the research potential of the electronic medium. World Book, Inc., and Encyclopædia Britannica, Inc., issued the texts of their print sets on CD-ROM in 1989 and 1993, respectively. In 1994 still illustrations were added to World Book's *Information Finder*, and in 1995 the *Britannica CD* was released with text supplemented by still illustrations and *Merriam-Webster's Collegiate Dictionary*. These reference works are now also available on DVD.

Online encyclopaedias. In 1983 the *Academic American Encyclopedia* became the first encyclopaedia to be presented to a mass market online by the licensing of its text to commercial data networks, which eventually included CompuServe and Prodigy Information Service. Nine years later *Compton's Encyclopedia* licensed its text to America Online, another commercial information provider.

In 1994 *Britannica Online* was released for subscription over the Internet, the global network of networks. In addition to the full text database and thousands of illustrations, *Britannica Online* served as a "gateway" to the World Wide Web by providing direct links to outside sources of information. (R.L.C./W.E.P./Ed.)

History of encyclopaedias

ENCYCLOPAEDIAS IN THE WEST

Early development. The first fragments of an encyclopaedia to have survived are the work of Speusippus (died 339/338 BC), a nephew of Plato's. Speusippus conveyed his uncle's ideas in a series of writings on natural history, mathematics, philosophy, and so forth. Aristotle's wide-ranging lectures at the Lyceum were equally influential, and he and Plato appear to have been the originators of the encyclopaedia as a means of providing a comprehensive cultural background.

The Greek approach was to record the spoken word. The Romans, on the other hand, aimed to epitomize existing knowledge in readable form. Their first known effort is the *Praecepta ad filium* ("Advice to His Son"; *c.* 183 BC), a series of letters (now lost) written by the Roman consul Cato the Censor to his son. Cato's intention was to provide a summary of useful information that could help in the process of living and in guiding and helping one's fellowmen. A more substantial attempt was made by the learned Latin writer Marcus Terentius Varro in his *Disciplinarum libri IX* ("Nine Books of Disciplines"), his *Rerum divinarum et humanarum antiquitates* ("The Antiquities of Things Divine and Human"), and his *Imagines*, which together covered the liberal arts, human efforts, the gods, and biographies of the Greeks and Romans.

Pliny's *Historia naturalis*

The most important Roman contribution was the *Historia naturalis* of Pliny the Elder, a vast work constituting a kind of classified anthology of information. Although undiscriminating in its record of fact and fancy, it was nevertheless very influential; the Latin grammarian and writer Gaius Julius Solinus drew nearly 90 percent of his 3rd-century *Collectanea rerum memorabilium* ("Collection of Memorabilia") from Pliny, and the *Historia naturalis* served as a major source for other encyclopaedias for at least the next 1,500 years. Even today it is still an important record for details of Roman sculpture and painting.

The statesman Cassiodorus, when he withdrew to the Vivarium in 551, dedicated this monastery to sacred and classical learning. His *Institutiones divinarum et saecularium*

By courtesy of the trustees of the British Museum; photograph, R.B. Fleming & Co.



Illustration from the entry on the winds in St. Isidore of Seville's *Etymologiae*, an edition published in Strasbourg *c.* 1473.

litterarum ("Institutes of Divine and Secular Literature") seems to have been designed to preserve knowledge in times that were largely inimical to it. In his encyclopaedia, Cassiodorus drew a clear distinction between the sacred and the profane, but the first Christian encyclopaedia to be compiled for the benefit of the newly converted Spanish population followed a different scheme. St. Isidore (*c.* 560–636) considered the liberal arts and secular learning to be the true basis of a Christian's education. His *Etymologiae* therefore paid much attention to practical matters and even included an etymological dictionary. This was in line with the thought of St. Jerome—on whose encyclopaedic *Chronicon* and *De viris illustribus* St. Isidore had drawn—who, in common with the early Christian Fathers, was eager to provide a basis for a Christian interpretation and organization of knowledge. This concept was much later to be renewed by the Catalan ecclesiastic Ramon Llull.

The development of the encyclopaedia during the next 500 years, though of social interest, was undistinguished from the point of view of scholarship. Rabanus Maurus (*c.* 776–856), one of the English scholar Alcuin's favourite pupils, compiled *De universo* ("On the Universe"), which, in spite of its being an unintelligent plagiarism of St. Isidore's work, had a lasting popularity and influence throughout the medieval period. A series of encyclopaedias of special subjects—undistinguished anthologies of classical and Christian writings on history, jurisprudence, agriculture, medicine, veterinary surgery, and zoology—was organized by the Byzantine emperor Constantine VII Porphyrogenitus (905–959). Michael Psellus (1018–96), a tutor of a later emperor, contributed a more interesting work, *De omnifaria doctrina,* in the form of questions and answers on both the humanities and science. At this time there was a growing influence on metropolitan and secular learning. In an attempt to counterbalance it, the brief but charming *Didascalion* of Hugh of Saint-Victor (*c.* 1096–1141), which paid much attention to practical matters as well as to the liberal arts, was soundly based on a profound classification of knowledge that influenced many later encyclopaedias. About this time an encyclopaedic dictionary known as *Suda,* or *Suidas,* broke with tradition by adopting alphabetical order for its contents. This had no effect on the plan of later encyclopaedias, but its contents included so much useful information that it has retained its importance as a source throughout the succeeding centuries.

Adoption of the alphabetical order in *Suda*

The *Liber floridus* (*c.* 1120) of Lambert of Saint-Omer is an unoriginal miscellany, but it has an interest of its own in that it discards practical matters in favour of metaphysical discussion and pays special attention to such subjects as magic and astrology. The greatest achievement of the 12th century was the *Imago mundi* of Honorius Inclusus. Honorius produced his "mirror of the world" for Christian, later abbot of St. Jacob, and drew on a far wider range of authorities than any of his predecessors. The arrangement of the first section on geography, astrology, and astronomy was sound; it started with the creation and worked down to individual countries and cities. This was followed by a "chronicle," and a third section provided a brief list of important events since the fall of Satan. Honorius accurately foresaw his book's fate: innumerable copies, unauthorized plagiarisms, incessant criticism, and incompetent additions for at least 200 years.

Probably the first encyclopaedia to be compiled by a woman, the *Hortus deliciarum* of the abbess Herrad (died 1195), comprised a magnificent illuminated manuscript with 636 miniatures, intended to help and edify the nuns in her charge. Bartholomaeus Anglicus based his *De proprietatibus rerum* (1220–40) on the works of St. Isidore and Pliny. It was designed for ordinary people and became Europe's most popular encyclopaedia for the next three centuries. But the outstanding achievement of the Middle Ages was the *Speculum majus* of Vincent of Beauvais. Vincent was not an original writer but he was industrious, and his work comprised nearly 10,000 chapters in 80 books; no encyclopaedia rivalled it in size until the middle of the 18th century. The work was very well balanced, almost equal space being allotted to the three sections. The "Naturale" dealt with God and man, the creation, and natural history. For this Vincent drew not only on Latin writings but also on Greek, Arabic, and Hebrew, which were at that time (through translations) making a very considerable impact on the thinking of the West. The "Doctrinale" covered practical matters as well as the scholastic heritage of the age. The "Historiale" included a summary of the first two sections and a history of the world from the creation to the times of St. Louis. A fourth section, "Morale," based principally on St. Thomas Aquinas, was added after Vincent's death. The influence of the *Speculum majus* was immediate and lasting. Translations were made into several languages, and complete reprints appeared as late as 1863–79. One of its many values is that it is a source for extracts from many documents of which no other parts have survived. Another is its detailed history of the second quarter of the 13th century.

Vincent's was the last major work of its kind. Later encyclopaedists began to compile for a wider public than the very limited world of religious communities. The first breakaway from Latin came with *Li livres dou trésor* ("Treasure Books") of Brunetto Latini (*c.* 1220–95), the master of Dante, and the Florentine poet and philosopher Guido Cavalcanti. Latini wanted to reach the mercantile and cultured classes of Italy; he therefore used French, their common language. The arrangement of his work was similar to Vincent's but his approach was concise. The language, the brevity, and the accuracy of his encyclopaedia had an immediate and wide appeal. A friend of Petrarch's, Pierre Bersuire, based his *Reductorium, repertorium et dictionarium morale utriusque testamenti* ("Moral Abridgment, Catalogue and Dictionary of Each Testament"; *c.* 1340) on Bartholomaeus' *De proprietatibus rerum.* In contrast to Latini's work, this was a return to the traditional, with its moralizings on the Bible, Ovid's *Metamorphoses,* and natural history, but it had a considerable success when printing was introduced, being issued 12 times by 1526.

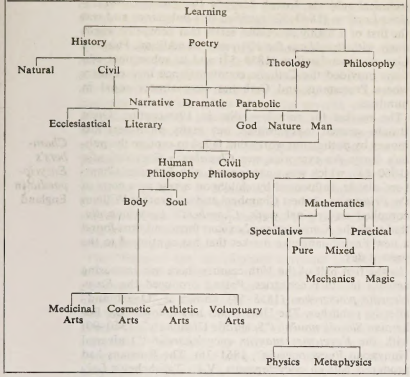
Brunetto Latini's breakaway from Latin

One of the most delightful of all encyclopaedias is the little *Margarita philosophica* that Gregor Reisch (died 1525) wrote for young people. In some 200 pages he contrived to cover in a very pleasing style the whole university course of the day, both the trivium and the quadrivium. The arrival of humanism is reflected in the *De disciplinis* of Juan Luis Vives, a pioneer in psychology and philosophical method; Vives grounded all his arguments on nature and made no appeal to religious authority. With the writing of the anonymous *Compendium philosophiae* (*c.* 1300) the concept of the modern scientific encyclopaedia was reached at last. It was the first encyclopaedia to adopt an inquiring and impartial attitude to the things described, and the old wives' tales that had filled so many pages of encyclopaedias from the time of Pliny onward were replaced by the latest scientific discoveries.

The first indigenous French encyclopaedia, the popular *Dictionarium historicum, geographicum et poeticum* ("Historical, Geographical, and Poetic Dictionary") of Charles Estienne (1504–64) was not published until 1553. For encyclopaedias in their own language, the French still had to rely on translations of the encyclopaedias of other nations, such as *Les diverses leçons* ("The Various Lessons"; 1552) of Pedro Mexia, a mediocre Spanish historian whose haphazard compilation was enormously popular in the 16th and 17th centuries.

The development of the modern encyclopaedia (17th–18th centuries). Francis Bacon's purpose in writing the *Instauratio magna* was "to commence a total reconstruction of sciences, arts, and all human knowledge, raised upon the proper foundations" in order to restore or cultivate a just and legitimate familiarity between things and the mind. Only a small part of this enormous work was ever completed, but the author had planned 130 sections divided into three main sections: external nature, man, and man's action on nature. From its proposed contents Bacon's intention was clearly to compile an encyclopaedia thoroughly scientific in character—"a thing infinite and beyond the powers of man"—that he himself recognized to be revolutionary in character. His most important contribution was, however, the devising of a new and thoroughly

Table 1: Francis Bacon's Classification of Knowledge



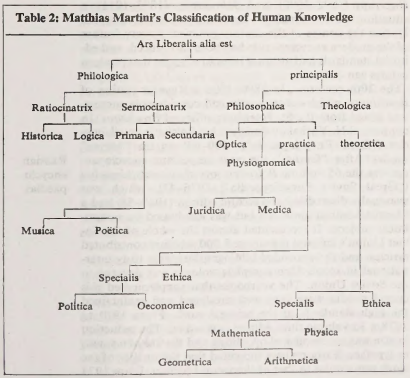
sound classification of knowledge that bears a remarkable resemblance to the classification put forward by Matthias Martini in his *Idea Methodica* (1606). Although Bacon was apparently unaware of this work, both philosophers were probably working from the same basic Platonic precepts. The results were profound: Diderot made a point of acknowledging the assistance Bacon's analysis of the structure of human knowledge had afforded him in planning the contents of the *Encyclopédie*, and Samuel Taylor Coleridge hailed "the coinciding precepts of the Athenian Verulam and the British Plato."

Bacon's influential classification

Only two more Latin encyclopaedias of any importance followed. Antonio Zara, bishop of Petina, compiled the *Anatomia Ingeniorum et Scientiarum* ("Anatomy of Arts and Sciences"; 1614), which was chiefly remarkable for the inclusion of an index. And Johann Heinrich Alsted, who, like Martini, came from Herborn, compiled an *Encyclopaedia* (1630) whose arrangement corresponds broadly to Matthias' classification of human knowledge.

Zara's and Alsted's encyclopaedias were organized systematically by classification. The turning point came with

Table 2: Matthias Martini's Classification of Human Knowledge



Louis Moréri's alphabetically arranged *Grand Dictionnaire historique* (1674), which was especially strong in geographical and biographical material. Its success was immediate; six editions were issued by 1691, each incorporating much new contemporary information. English editions followed in 1694, 1701, and (a supplement) 1705. Other encyclopaedias in England, Germany, Switzerland, and The Netherlands acknowledged its inspiration. The alphabetically arranged encyclopaedia in the vernacular had almost won the day, in spite of the German scholar Daniel George Morhof's modest success with his ill-balanced *Polyhistor Literarius, Philosophicus, et Practicus* ("Literary, Philosophical, and Practical History"; 1688–1708).

If there was any doubt concerning the more popular form of the encyclopaedia, the issue of Antoine Furetière's *Dictionnaire universel des arts et sciences* (1690) confirmed the true nature of public taste. Furetière not only compiled a fine encyclopaedic dictionary, but he emphasized the arts and the sciences, thus reflecting the rapidly growing public interest in modern culture, science, and technology. If confirmation were still needed, the Académie Française's commissioning of Thomas Corneille to compile *Le Dictionnaire des arts et des sciences* (1694), with its thorough and authoritative treatment of these new encyclopaedic features, demonstrated that even the more conservative scholars were by now keenly aware that a new spirit had arisen. The period of the clerical encyclopaedia had ended, as the Franciscan friar Vincenzo Maria Coronelli found when his *Biblioteca Universale Sacro-Profano* (1701–06) ceased publication at volume 7 of a projected 45.

Furetière's modern *Dictionnaire universel*

Pierre Bayle, in his *Dictionnaire historique et critique* (1697), achieved a most remarkable tour de force. Although his encyclopaedia purported to be an updating of the information in Moréri, the entries were largely unexceptionable. The real originality of his work lies in the profuse and scholarly footnotes and the commentaries that at times were an amazing mixture of skepticism, blasphemy, and ribaldry. Bayle challenged orthodox ideas; his brilliant mind spared nothing. This approach heralded that of Diderot, and the distinguished writers who revised later editions—Prosper Marchand and Pierre Desmaizeaux—continued in the same style.

The *Lexicon Technicum* (1704) of John Harris represented the powerful impact of the work of the Royal Society (founded 1660). Here was all the equipment of the modern encyclopaedia: excellent engraved plates, clear practical text, bibliographies appended to the more important articles. So far, England had had to make do with translations of French encyclopaedias. Harris' emphasis on the need to include scientific and technical subjects helped to reverse the trend. This process was completed by the issue of Ephraim Chambers' *Cyclopaedia* (1728). Like Harris, Chambers omitted people in favour of more information on the arts and sciences, and he paid more attention to clear expositions of ancient and modern philosophical systems. His admirably cross-referenced work is universally recognized as the father of the modern encyclopaedia.

The French were well aware of these developments. By 1744 five editions of Chambers' *Cyclopaedia* had been issued. The Paris publisher André Le Breton saw a ready market for a translation. The first proposals were a failure, however, and Diderot was enlisted to plan what at that time was still essentially a translation on a much broader basis. Under the hands of Diderot and d'Alembert the concept changed. The *Encyclopédie* (1751–65) was a philosophical undertaking carried out on a gigantic scale, and much of the writing was of a high standard. To the orthodox, it appeared that the project had got out of hand, but there were 2,000 subscribers to the first volume, and the subsequent scandals over the irreverent, authority-challenging articles only added to the number of purchasers. The equivocal attitude of high dignitaries in both church and court and the growing public dislike of the encyclopaedia's chief critics—the Jesuits—led to a complex situation in which official disapproval and substantial private encouragement caused the production and fortunes of the *Encyclopédie* and its producers to lurch dangerously from one crisis to another. Curiously, Diderot

Diderot's monumental *Encyclopédie*

did nothing to further the physical development of the encyclopaedia; his contribution was to fire men's minds with a willful guidance that conformed to the country's increasingly revolutionary spirit. As Voltaire said: "this vast and immortal work seems to reproach mankind's brief life span."

The shortcomings of the *Encyclopédie* were obvious. The essential ingredients of an encyclopaedia, the entries on every conceivable subject, had been sacrificed to make place for lengthy polemics on the controversial topics of the day. The *Encyclopædia Britannica* was intended to improve on this, and, with all its shortcomings, the first edition (1768–71) did exactly that. The achievement of its editors was the more remarkable in that there were already several English encyclopaedias on the market. The Scottish encyclopaedia, however, reflected the taste of the day better than any of its competitors, for it was a completely new work and not just a remaking of Chambers and Harris. There was much to criticize in the first edition, but the second (1777–84; dated 1778–83) was greatly improved, as were following editions.

Meanwhile, Germany, at first largely dependent on translations of foreign encyclopaedias, had produced the scholarly "Hübner" (1704), as it was known from the name of the author of the preface in this first of the *Konversationslexikon* type. The form appealed to the rapidly growing middle class of the country, who welcomed encyclopaedias designed to provide them with an adequate cultural background for polite society. Johann Theodor Jablonski's illustrated *Allgemeines Lexicon* (1721) continued in this same style, and there were similar works compiled by the Swiss theologian and philologist Jakob Christoph Iselin and Antonius Moratori (1727). Johann Heinrich Zedler's huge *Grosses vollständiges Universal-Lexicon* ("The Great Comprehensive Universal Lexicon"; 1732–50) was in the older tradition but is important for its accuracy and its biographical and bibliographical material. An attempt to produce a German type of the *Encyclopédie* in 1778–1807 was, however, a failure. Friedrich Arnold Brockhaus recognized the real need of the German people. Reworking Renatus Gotthelf Löbel's bankrupt encyclopaedia, he produced his first *Konversations-Lexikon* (1796–1811; later named *Brockhaus Enzyklopädie*), thereby setting the pattern for at least half of all succeeding encyclopaedias throughout the Western world. Brief, well-designed articles tightly packed with facts, comprehensive coverage, and a reputation for accuracy and up-to-dateness were the ingredients for one of the most successful of encyclopaedias.

Brockhaus' *Konversations-Lexikon*

The 19th century. Having served a long apprenticeship as a reviser of Chambers' *Cyclopaedia,* Abraham Rees at last produced a completely original and finely illustrated work, *The New Cyclopaedia* (1802–20), the only serious rival to the *Britannica* in a generation that saw some dozen "new" encyclopaedias rise and fall. What might have been the greatest encyclopaedia of the century, the *Encyclopaedia Metropolitana* (1817–45), failed miserably because of the early withdrawal of its designer, Samuel Taylor Coleridge, and subsequent financial troubles; but from it came the most notable contribution to the philosophy of encyclopaedia making since Bacon—Coleridge's profound treatise "On Method" (1818).

To the principal influences on the compilation of encyclopaedias—Bacon, Diderot, the *Britannica,* and Brockhaus—must be added that of the Frenchman Pierre Larousse. His completely original approach to encyclopaedia making has given the series of encyclopaedias that bear his name a unique reputation. Emphasis throughout has been on readability; style has never been sacrificed to conciseness, and the successive editors of *Larousse* have paid very close attention to the changing public taste among French readers.

The advent of Noah Webster was fully as epoch-making as that of Brockhaus and Larousse. Webster's informative *American Dictionary of the English Language* (1828) was encyclopaedic in character, but he avoided the long entries for the more important subjects that were such a feature of *Larousse.* Webster's approach appealed to the American taste and captured a huge market that has only increased with the years.

Brockhaus soon faced opposition, for his encyclopaedia was stronger on the humanities than on scientific and technical subjects. Joseph Meyer's *Der grosse Conversations-Lexikon* (1840–52) rectified this imbalance and was the first of a highly successful series that competed vigorously with *Brockhaus* for 100 years. In addition, Herder's *Conversations-Lexikon* (1853–57) and its subsequent editions provided the Catholic counterbalance in a country where Protestants and Catholics were almost equal in numbers.

The market for encyclopaedias in 19th-century Great Britain seemed inexhaustible, but many publishers lost money by putting out works that failed to capture the public's fancy. An exception was *Chambers's Encyclopaedia* (1860–68), which was unconnected with Ephraim Chambers' classic. Influenced by childhood access to a copy of the *Britannica,* Robert Chambers and his brother William compiled an original work, *Chambers's Encyclopaedia,* that took the *Konversations-Lexikon* form and thus found a new English-language market that has continued to the present day.

Chambers's Encyclopaedia in England

In the first half of the 19th century there was increasing activity in other countries. Poland produced the *Encyklopedia powszechna* (1858–68), known as "Orgelbrand" after its publisher. The Hungarians had followed the Bohemian *Slovník naučný* ("Scientific Dictionary"; 1860–90) with the *Egyetemes magyar encyclopaedia* ("Universal Hungarian Encyclopaedia"; 1861–76). The Russians had produced half an encyclopaedia, V.N. Tatishchev's *Leksikon rossyskoy* ("Russian Lexicon"), in 1793 and then issued A. Starchevsky's *Spravochny entsiklopedichesky slovar* ("Encyclopaedic Reference Dictionary"; 1847–55) on the *Brockhaus* model. More important was the famous *Entsiklopedichesky slovar* ("Encyclopaedic Dictionary"; 1895), which became known as "Granat" after the Granat Russian Bibliographical Institute that produced it. A later edition (1910–48) of "Granat," in 58 volumes, was not exported from the Soviet Union. Modelled on the *Britannica,* this edition contained many important articles, such as Lenin's contribution on Marx and on "The Russian 19th-Century Agrarian Problem." Successive ideological changes in Russian society caused many changes in the text of "Granat," and it long remained one of the most inaccessible of all Russian encyclopaedias outside the Soviet Union.

Larousse did not go unchallenged. Inspired by the French politician Ferdinand-Camille Dreyfus, *La Grande Encyclopédie* (1886–1902) provided France with a superb, authoritative, and comprehensive work, well documented and of excellent scholarship throughout. In Denmark the century ended with the issue of no fewer than three new good multivolume encyclopaedias: *Allers* (1892–99), *Hagerups* (1892–1900), and *Salmonsens* (1893–1911), a situation without parallel in the history of encyclopaedias. During the course of the century practically every feature of the modern encyclopaedia had been introduced, and editorial standards had at times risen to a height that modern editors can only envy.

The 20th century. In 1890–1906 a Russian edition of *Brockhaus,* which subsequently had considerable success, was issued from the St. Petersburg office of *Brockhaus.* In contrast, S.N. Yushakov designed his *Bolshaya entsiklopedya* ("Great Encyclopaedia"; 1900–09) on the "Meyer" model. After "Granat" the next important encyclopaedia was the 65-volume *Bolshaya sovetskaya entsiklopedya* ("Great Soviet Encyclopaedia"; 1926–47), which was eventually discredited; the second edition (1949–58) had a Marxist-Leninist approach but was less biased on nonpolitical subjects. It represented almost the whole of the Soviet Union's cultural resources: 8,000 scholars contributed articles, and the appended bibliographies were truly international in scope. One complete volume was devoted to the Soviet Union. The yearbooks that supplemented this encyclopaedia were very well produced and maintained the high standards of the original work. From 1970 to 1978 a 30-volume third edition was issued. The reduction in size was accomplished by editing and the use of a smaller typeface. Early reviews indicated that the quality of the work was similar to that of the second edition. From 1973

Russian encyclopaedias

to 1983 Macmillan released an English translation of the third Russian edition. There was also a series of editions of the much smaller *Malaya sovetskaya entsiklopedya* ("The Little Soviet Encyclopaedia"), first issued in 1928–31.

In the United States, the first edition of *The New International Encyclopaedia* was issued in 1902–04 and was subsequently supplemented by yearbooks. *The Encyclopedia Americana*, which traced its ancestry to an English-language adaptation (1829–33) of the seventh edition of *Brockhaus*, took on new strength in 1902 when the editor of *Scientific American*, Frederick C. Beach, was appointed editor of the *Americana*. It has enjoyed growing success through its policy of following the continuous revision system, and yearbooks have supplemented it from 1923 onward. In 1950–51 a completely new American work, *Collier's Encyclopedia*, appeared in 20 volumes, and subsequent editions were supplemented by yearbooks beginning in 1960. *Collier's* was noted for its large number of illustrations and maps.

The "Espasa," the *Enciclopedia universal ilustrada europeo-americana* (1905–33), like the *Enciclopedia italiana*, eschewed revision in favour of a series of sizable supplements. One complete volume was devoted to Spain and was separately revised and reissued from time to time. A smaller encyclopaedia, the *Salvat universal diccionario enciclopédico* (first issued in 1907–13), was revised at frequent intervals. Another major Spanish encyclopaedia, the *Enciclopedia labor* (first issued 1955–60), devoted one volume each to major subject areas, and an index volume provided the key to the total contents. This encyclopaedia was notable for the attention it paid to every Spanish-speaking part of the world.

One of the most important of all encyclopaedias, the *Enciclopedia italiana di scienze, lettere ed arti* (1929–39), was famous for its lavish production, its superb illustrations, and its lengthy, scholarly, and well-documented articles. Even its defense of fascist ideology was not allowed to impinge on the general impartiality of the text. Supplements were issued after World War II. The postwar *Dizionario enciclopedico italiano* (1955–61), issued by the same publishers, was a much smaller, well-illustrated work. The *Enciclopedia europea* was released in Milan between 1976 and 1984. Although consisting largely of brief articles, it had numerous signed long articles of good quality. In Germany, the three giants of the German encyclopaedia world—*Brockhaus*, "Meyer," "Herder"—continued to produce new editions in the 20th century.

Italian encyclopaedias

In spite of the continuing popularity of *Larousse*, France produced several other encyclopaedias of note in the 20th century. The *Encyclopédie française* (begun 1935) was an outstanding collection of monographs by well-known scholars and specialists, arranged in classified form and available in loose-leaf binders, supplemented by a continuously revised index. Its 21 volumes, each under the direction of a different authority, dealt with (1) human mental tools (logical thought, language, and mathematics), (2) physics, (3) heaven and earth, (4) life, (5) living beings, (6) human beings (the healthy and the sick), (7) the human species, (8) the study of the mind, (9) the economic and social universe, (10) the modern state, (11) international life, (12) chemical science and industry, (13) industry and agriculture, (14) daily life, (15) education and learning theory, (16–17) arts and literatures, (18) the written word, (19) philosophy and religion, and (20) the world in its development (history, evolution, prospective); the 21st volume contained an index. The articles were notable for their almost total concentration on contemporary issues in the fields considered.

The *Encyclopédie de la Pléiade* (begun 1955) was an encyclopaedic series, each work (some in more than one volume) being a self-contained treatment of a broad subject field written in narrative form.

One of the most interesting encyclopaedias of the 20th century was the *Encyclopaedia universalis* (first issued 1968–74), edited by Claude Grégory and owned by the French Book Club and Encyclopædia Britannica, Inc. This work, inspired by *L'Encyclopédie*, eschewed the inclusion of minor items in favour of extensive and very well-illustrated articles on important subjects, and it paid special attention to modern science and technology. It was accompanied by a symposium and an elaborate thesaurus-index.

Co-production

Encyclopaedia universalis was doubly notable as the product of a publishing arrangement known as "coproduction." The term is applied in general to the collaborative efforts of publishing concerns in two or more countries that have combined forces to produce an encyclopaedia for sale in one of the countries or, with modifications to the volumes, in two or several countries. Successful examples of coproduction included the *Buritanika Kokusai Dai Hyakka Jiten* (*Britannica International Encyclopædia*) in Japan and the *Concise Encyclopædia Britannica* in China (both discussed below).

Encyclopædia Britannica, Inc., in addition, was similarly involved in the development of the Taiwan edition of the *Concise Encyclopædia Britannica* in traditional Chinese characters (1989); the Korean *Britannica World Encyclopædia*; the Turkish *AnaBritannica*; two Spanish-language encyclopaedias, the *Enciclopedia Barsa de consulta fácil* and the *Enciclopedia hispánica*; the Portuguese-language *Enciclopédia Barsa*; *Enciclopédia Mirador Internacional*, a scholarly set first published in Brazil in 1975; and *Il Modulo*, published in Italy. Other major instances of coproduction involve the interesting *The New Caxton Encyclopedia*, which originated in Italy with Istituto Geografico de Agostini and subsequently appeared in Great Britain, first sold in serial parts as *Purnell's New English Encyclopedia* (1966) and then in a bound set of 18 volumes (1966); in France there appeared a version called *Alpha: La Grande Encyclopédie Universelle en Couleurs*, and in Spain a version called *Monitor*. The American-made *Random House Encyclopedia* was adapted and translated in various languages and under various names for distribution in several countries.

National encyclopaedias

By the 21st century virtually every Western country had domestically produced or released either a single-volume or multivolume encyclopaedia in its native tongue. Some of the more notable sets in the 20th century were:

Bulgaria: *Kratka bŭlgarska entsiklopediia* (1963–69).

Czechoslovakia: *Ottův slovník naučný* (1888–1909); *Masarykův slovník naučný* (1925–33); *Nový velký ilustrovaný slovník naučný* (1929–34); *Komenského slovník naučný* (1937–38); *Přiruční slovník naučný* (1962–67).

Denmark: *Gyldendals leksikon* (1977–78; the latest in a series starting in 1931–32); *Raunkjaers konversationsleksikon* (1948–57); *Gyldendals store opslagsbog* (1967–70).

Estonia: *Eesti nõukogude entsüklopeedia* (first published 1968–78).

Finland: *Otavan iso tietosanakirja: encyclopaedia fennica* (1960–65); *Uusi tietosanakirja* (1960–66; the latest in a series starting in 1931–39).

Greece: *Megalē hellēnikē enkyklopaideia* (first published 1926–34); *Eleutheroudakē enkyklopaidikon lexikon* (1927–31).

Hungary: *Révai nagy lexikona* (1911–35); *Új magyar lexikon* (1959–81); *Új idők lexikona* (1936–42).

The Netherlands: *Eerste nederlandse systematisch ingerichte encyclopaedie* ("ENSIE"; 1946–60); *Grote Winkler Prins encyclopedie* (1977–84; the latest in a series starting in 1870–82); *Oosthoeks encyclopedie* (1968–73; the latest in a series starting in 1916–23).

Lithuania (published in Boston): *Lietuvių enciklopedija* (1953–69).

Norway: *Aschehougs konversasjonsleksikon* (1968–73; the latest in a series starting in 1907–13); *Norsk konversasjonsleksikon, Kringla heimsins* (first published 1931–34); *Norsk allkunnebok* (1948–66).

Poland: *Wielka encyklopedia powszechna PWN* (1962–70).

Romania: the Romanian Academy's *Dicţionar enciclopedic român* (1962–66).

Sweden: *Bonniers konversations lexikon* (1922–29); *Focus uppslagsbok* (first published 1958–60).

Yugoslavia (now split into the countries of Bosnia and Herzegovina, Croatia, Macedonia, Serbia and Montenegro, and Slovenia): *Enciklopedija Jugoslavije* (first published

1955–71); *Enciklopedija leksikografskog zavoda* (first published 1955–64); *Pomorska Enciklopedija* (1954–64); *Hrvatska enciklopedija* (1941–45; unfinished, A–Elektrika only).

ENCYCLOPAEDIAS IN THE EAST

China. The contribution from the East to the history of encyclopaedias is distinctive and covers a longer period than that of the West. The Chinese have produced encyclopaedias for approximately 2,000 years, but traditionally they differ from the modern Western encyclopaedia in that they are mainly anthologies of significant literature with some elements of the dictionary. Compiled by scholars of eminence, they have been revised rather than replaced over hundreds of years. In the main, they followed a classified form of arrangement; very often their chief use was to aid candidates for the civil service. The first known Chinese encyclopaedia, the *Huang-lan* ("Emperor's Mirror"), was prepared by order of the emperor in about AD 220. No part of this work has survived. Part of the *Pien-chu* ("Stringed Pearls of Literature"), prepared around 600, is still extant. About 620 the *I-wen lei-chü* ("Anthology of Art and Literature") was prepared by Ou-yang Hsün (557–641) in 100 chapters divided into 47 sections. The *Pei-t'ang shu-ch'ao* ("Extracts for Books") of Yü Shih-nan (558–638) was more substantial and paid particular attention to details of the organization of public administration. An annotated edition, edited by K'ung Kuang-t'ao, was published in 1880.

The earliest Chinese encyclopaedia

The *Ch'u-hsüeh chi* ("Entry into Learning") was a modest work compiled about 700 by Hsü Chien (659–729) and his colleagues. A more important book was the *T'ung-tien* ("Comprehensive Statutes") compiled by Tu Yu (735–812), a writer on government and economics. Completed in about 801, it contained nine sections: economics, examinations and degrees, government, rites and ceremonies, music, the army, law, political geography, national defense. In 1273 it was supplemented by Ma Tuan-lin's enormous and highly regarded *Wen hsien t'ung k'ao* ("General Study of the Literary Remains"), which included a good bibliography. Supplements to this work were published in the 17th, 18th, and 20th centuries. Under the order of the second Sung emperor, Sung T'ai Tsung, the statesman Li Fang organized the compilation of the vast *T'ai-p'ing yü-lan* ("Emperor's Mirror"), which included extracts from many works of literary and scientific standing that are no longer extant. In 1568–72 the *T'ai-p'ing yü-lan* was revised and reprinted from movable type; a new edition revised by Yüan Yüan appeared in 1812. The *Ts'e-fu yüan-kuei* (*c.* 1013), particularly strong in historical and biographical subjects, was almost as large as the *T'ai-p'ing yü-lan.*

The historian Cheng Ch'iao (1108–66) compiled the *T'ung chih* ("General Treatises"), an original work with a strong personal contribution: the printed edition (1747) was in 118 volumes. One of the richest and most important of all Chinese encyclopaedias, the *Yü-hai* ("Sea of Jade"), was compiled about 1267 by the renowned Sung scholar Wang Ying-lin (1223–92) and was reprinted in 240 volumes in 1738.

What was probably the largest encyclopaedia ever compiled, the *Yung-lo ta-tien* ("Great Handbook"), was issued at the beginning of the 15th century. Unfortunately, only a very small part of its 22,937 chapters has survived; these were published in 1963. A number of small encyclopaedias were issued in the 16th century, but the next important event was the publication of the small but profusely illustrated *San ts'ai t'u-hui* (1607–09), compiled by Wang Ch'i and his son Wang Ssu-i. In 1704–11 the Chinese literary encyclopaedia *P'ei-wen yün-fu* was compiled by order of the emperor K'ang-hsi; this was supplemented by the *Yün fu shi I* (1720). Other works ordered by the emperor include the *Pien-tzu lei-pien* (1726) and the *Tzu shih ching hua* (1727). In 1726 the huge *Ku-chin t'u-shu chi-ch'eng* ("Collection of Pictures and Writings") was published by order of the emperor. Edited by the scholar Ch'en Meng-lei, it filled over 750,000 pages and attempted to embody the whole of the Chinese cultural heritage.

World's largest encyclopaedia

At the turn of the century, a number of encyclopaedias were issued. Wang Chi's *Shih wu yüan hui,* which covered well over 2,000 topics, was compiled in 1796. Lu Feng-tso's *Hsiao chih lu* (1804) is particularly valuable for its attention to technical terms, which previous works had ignored. Ch'en Wei's *Ching Chuan Il* (1804) concentrated on history and the great Chinese classics, whereas Wang Ch'eng-lieh's *Ch'i ming chi shu* (1806) is stronger in biographical material. Tai Chao-ch'un compiled the *Ssu shu wu ching lei tien chi ch'eng* (1887), a historical work for the use of civil-service candidates. Wei Sung's *I shih chi shih* (1888) had actually been compiled 65 years previously, but it paid far more attention to practical matters. The *Chiu T'ung T'ung* (1902) of Liu K'o-i was in large measure a reassembly of material in the older encyclopaedias in a more efficient classification. A more important work of the period is the largely historical and biographical *Erh shih ssu shih chiu t'ung cheng tien lei yao ho pien* (1902). The *Ch'ing ch'ao hsü wen hsien t'ung k'ao* (1905), compiled by Liu Chin Tsao, was revised and enlarged in 400 volumes in 1921. It includes contemporary material on fiscal, administrative, and industrial affairs and gives some attention to technical matters. Lu Erh-k'uei's *Tz'u-yüan* (1915), with a supplement issued in 1931, was the first really modern Chinese encyclopaedia and set the style for nearly all later works of this nature.

In 1980, officials of the Greater Encyclopedia of China Publishing House and Encyclopædia Britannica, Inc., announced an agreement under which the *Micropædia* of the 15th edition of *Encyclopædia Britannica* would be translated into Chinese for distribution in China. The 10-volume set for this project, *The Concise Encyclopædia Britannica,* was published serially in 1985–86.

Japan. In the Edo, or Tokugawa, era (1603–1867) there appeared a kind of encyclopaedia that consisted of extracts of major works in Japanese and Chinese. *Kojiruien* (51 volumes, 1879–1914) and *Nihon-hyakka-daijiten,* or the "Great Japanese Encyclopaedia" (10 volumes, 1908–19) were somewhat more akin to modern encyclopaedias but were mostly compilations of scientific works. More complete general encyclopaedias appeared in the Showa period (1926–89); *Dai-hyakka* (28 volumes, 1931–35), *Kokumin-hyakka* (15 volumes, 1934–37), *Sekai-daihyakka* (24 volumes, 1955–68), and *Japonica* (19 volumes, 1967–72) are examples of well-compiled works. The *Buritanika Kokusai Dai Hyakka Jiten,* or *Britannica International Encyclopædia* (29 volumes), which began publication in 1972 and was completed in 1975, was the joint creation of Encyclopædia Britannica, Inc., and the Tokyo Broadcasting System acting together as TBS/Britannica Company, Tokyo. Unlike most Japanese-language encyclopaedias, which consist largely of simple short entries, its main body consists of 20 volumes of lengthy systematic entries (the main body was fully revised in 1988). Other sections of the four-part set include a six-volume reference guide, consisting of many thousands of short factual entries; a reader's guide; a study guide; and an index. There are also supplemental yearbooks.

The encyclopaedias of the Showa period

The Arab world. The early encyclopaedias written in Arabic can be roughly divided into two classes: those designed for people who wished to be well informed and to make full use of their cultural heritage, and those for the rapidly growing number of official administrators. The latter type of encyclopaedia originated when the Arabs established their rule through so many parts of the Mediterranean region. The first true encyclopaedia was the work of Ibn Qutayba (828–889), a teacher and philologist, who dealt with his topics by quoting traditional aphorisms, historical examples, and old Arabic poems. The arrangement and contents of his *Kitāb 'Uyūn al-Akhbār* ("The Best Traditions") set the pattern for many later encyclopaedias. The 10 books were arranged in the following order: power, war, nobility, character, learning and eloquence, asceticism, friendship, prayers, food, women. Ibn 'Abd Rabbih of Córdoba improved on Ibn Qutayba's work in his *'Iqd* ("The Jewelled Necklace") by including more contemporary items of note.

Work of Ibn Qutayba

What has often mistakenly been referred to as the first encyclopaedia, the *Mafātiḥ al-'Ulūm* ("Key to the Sciences"), was compiled in 975–997 by the Persian scholar and statesman al-Khwārizmī, who was well aware

of the content of the more important Greek writings. He divided his work into two sections: indigenous knowledge (jurisprudence, scholastic philosophy, grammar, secretarial duties, prosody and poetic art, history) and foreign knowledge (philosophy, logic, medicine, arithmetic, geometry, astronomy, music, mechanics, alchemy). The Ikhwān aṣ-Ṣafā' ("Sincere Brethren"), a religious or political party founded at Basra in the 10th century, published the *Rasā'il Ikhwān aṣ-Ṣafā'*, a remarkable work that consisted of 52 pamphlets written by five authors, comprising all the knowledge available in their milieu. The work included (1) mathematics, geography, music, logic, and ethics; (2) the natural sciences and philosophy; (3) metaphysics; and (4) religion, astrology, and magic. A complete edition was published in 1887–89.

The Egyptian historian and civil servant an-Nuwairi (1272–1332) compiled one of the best known encyclopaedias of the Mamlūk period, the *Nihāyat al-'arab fī funūn al-adab* ("The Aim of the Intelligent in the Art of Letters"), a work of almost 9,000 pages. It comprised: (1) geography, astronomy, meteorology, chronology, geology; (2) man (anatomy, folklore, conduct, politics); (3) zoology; (4) botany; (5) history. A complete edition was issued in 1923. The *Masālik al-abṣār* ("Sight-Seeing Journeys") of al-'Umarī (1301–48) was chiefly strong on history, geography, and poetry. A third Egyptian, al-Kalka-shandī (died 1418), compiled a more important and well-organized encyclopaedia, *Ṣubḥ al-a'shā,* that covered geography, political history, natural history, zoology, mineralogy, cosmography, and time measurement. Ibshīhī (flourished 1440) compiled a very individual encyclopaedia, the *Mustatraf* ("Spiritual Discoveries"), that covered the Islāmic religion, conduct, law, spiritual qualities, work, natural history, music, food, and medicine. At the turn of the Arab fortunes, Ibshīhī had recapitulated all that was best in their culture.

15th- and 16th-century Arabic encyclopaedias

The Persian lawyer ad-Dauwānī (1427–1501) published a kind of encyclopaedia, entitled *Unmūdaj al-'ulūm,* that consisted of documented questions and answers and technical inventions on a very wide range of subjects. As-Sīrazī (died 1542) soon issued a refutation to it, the *Maqālatar radd 'alā unmūdaj al-'ulum al-Galā'ija.* The *Magma' multaqat az-zuhūr birauḍa min al-manẓūm wal mantur* (1524) of al-Ḥanafī comprised an encyclopaedic survey and description of the various branches of knowledge, with an appendix containing an alphabetical list of the names of God. In Lebanon, Buṭrus al-Bustānī and his sons compiled the *Dā'irat al-ma'ārif* (1876–1900). A second edition (1923–25) was prepared by Muḥammad Farid Wajdi, and a third edition was begun by Fu'ād Afrām al-Bustānī in 1956. Arabic encyclopaedias, both general and topical, were widely available by the start of the 21st century.

Other areas. Other important encyclopaedias from the East include:

Burmese: the Burma Translation Society's *Myanma swezon kyan/Encyclopaedia Burmanica* (begun 1954).

Hebrew: *ha-Entziqlopedia ha-'Ivrit* (*Encyclopaedia Hebraica,* begun 1949); *Entziqlopedia kelalit Massadah* (1958–60).

Indonesian: *Ensiklopedia Indonesia* (1954).

Sinhalese: *Sinhalese Encyclopedia* (begun 1963).

(R.L.C./W.E.P./Ed.)

DICTIONARIES

The distinction between a dictionary and an encyclopaedia is easy to state but difficult to carry out in a practical way: a dictionary explains words, whereas an encyclopaedia explains things. Because words achieve their usefulness by reference to things, however, it is difficult to construct a dictionary without considerable attention to the objects and abstractions designated. Nonetheless, while a modern encyclopaedia may still be called a dictionary, no good dictionary has ever been called an encyclopaedia.

Historical background

FROM CLASSICAL TIMES TO 1604

In the long perspective of human evolutionary development, dictionaries have been known through only a slight fraction of language history. People at first simply talked without having any authoritative backing from reference books. A short Akkadian word list, from central Mesopotamia, has survived from the 7th century BC. The Western tradition of dictionary making began among the Greeks, although not until the language had changed so much that explanations and commentaries were needed. After a 1st-century-AD lexicon by Pamphilus of Alexandria, many lexicons were compiled in Greek, the most important being those of the Atticists in the 2nd century, that of Hesychius of Alexandria in the 5th century, and that of Photius and the *Suda* in the Middle Ages. (The Atticists were compilers of lists of words and phrases thought to be in accord with the usage of the Athenians.)

Because Latin was a much-used language of great prestige well into modern times, its monumental dictionaries were important and later influenced English lexicography. In the 1st century BC, Marcus Terentius Varro wrote a treatise *De lingua Latina;* the extant books of its section of etymology are valuable for their citations from Latin poets. At least five medieval scholastics—Papias the Lombard, Alexander Neckam, Johannes de Garlandia (John Garland), Hugo of Pisa, and Giovanni Balbi of Genoa—turned their attention to dictionaries. The mammoth work of Ambrogio Calepino, published at Reggio (now Reggio nell'Emilia), in 1502, incorporating several other languages besides Latin, was so popular that "calepin" came to be an ordinary word for a dictionary. A Lancashire will of 1568 contained the provision: "I wyll that Henry Marrecrofte shall have my calapyne and my paraf rasies." This is an early instance of the tendency that, several centuries later, caused people to say, "Look in Johnson" or "Look in Webster."

Interlingual dictionaries

Because language problems within a single language do not loom so large to ordinary people as those that arise in the learning of a different language, the interlingual dictionaries developed early and had great importance. The corporation records of Boston, Lincolnshire, have the following entry for the year 1578:

> That a dictionarye shall be bought for the scollers of the Free Scoole, and the same boke to be tyed in a cheyne, and set upon a deske in the scoole, whereunto any scoller may have accesse, as occasion shall serve.

The origin of the bilingual lists can be traced to a practice of the early Middle Ages, that of writing interlinear glosses—explanations of difficult words—in manuscripts. It is but a step for these glosses to be collected together at the back of a manuscript and then for the various lists—glossaries—to be assembled in another manuscript. Some of these have survived from the 7th and 8th centuries—and in some cases they preserve the earliest recorded forms in English.

The first bilingual glossary to find its way into print was a French–English vocabulary for the use of travellers, printed in England by William Caxton without a title page, in 1480. The words and expressions appeared in parallel columns on 26 leaves. Next came a Latin–English vocabulary by a noted grammarian, John Stanbridge, published by Richard Pynson in 1496 and reprinted frequently. But far more substantial in character was an English–Latin vocabulary called the *Promptorius puerorum* ("Storehouse [of words] for Children") brought out by Pynson in 1499. It is better known under its later title of *Promptorium parvulorum sive clericorum* ("Storehouse for Children or Clerics") commonly attributed to Geoffrey the Grammarian (Galfridus Grammaticus), a Dominican friar of Norfolk, who is thought to have composed it about 1440.

The next important dictionary to be published was an English–French one by John (or Jehan) Palsgrave in 1530, *Lesclaircissement de la langue francoise* ("Elucidation of the French Tongue"). Palsgrave was a tutor of French

in London, and a letter has survived showing that he arranged with his printer that no copy should be sold without his permission,

> lest his proffit by teaching the Frenche tonge myght be mynished by the sale of the same to suche persons as, besids hym, wern disposed to studye the sayd tongue.

A Welsh–English dictionary by William Salesbury in 1547 brought another language into requisition: *A Dictionary in Englyshe and Welshe moche necessary to all suche Welshemen as wil spedly learne the Englyshe tõgue.* The encouragement of Henry VIII was responsible for an important Latin–English dictionary that appeared in 1538 from the hand of Sir Thomas Elyot. Thomas Cooper enlarged it in subsequent editions and in 1565 brought out a new work based upon it—*Thesaurus Linguae Romanae et Britannicae* ("Thesaurus of the Roman Tongue and the British"). A hundred years later John Aubrey, in *Brief Lives,* recorded Cooper's misfortune while compiling it:

Thomas Cooper and his *Thesaurus*

> His wife . . . was irreconcileably angrie with him for sitting-up late at night so, compileing his Dictionary. . . . When he had halfe-donne it, she had the opportunity to gett into his studie, tooke all his paines out in her lap, and threw it into the fire, and burnt it. Well, for all that, that good man had so great a zeale for the advancement of learning, that he began it again, and went through with it to that perfection that he hath left it to us, a most usefull worke.

More important still was Richard Huloet's work of 1552, *Abecedarium Anglo-Latinum,* for it contained a greater number of English words than had before appeared in any similar dictionary. In 1556 appeared the first edition by John Withals of *A shorte Dictionarie for Yonge Beginners,* which gained greater circulation (to judge by the frequency of editions) than any other book of its kind. Many other lexicographers contributed to the development of dictionaries. Certain dictionaries were more ambitious and included a number of languages, such as John Baret's work of 1573, *An Alvearie: or triple Dictionarie, in Englishe, Latin, and French.* In his preface Baret acknowledged that the work was brought together by his students in the course of their exercises, and the title *Alvearie* was to commemorate their "beehive" of industry.

The first rhyming dictionary

The first rhyming dictionary, by Peter Levens, was produced in 1570—*Manipulus Vocabulorum. A Dictionarie of English and Latine wordes, set forthe in suche order, as none heretofore hath ben.*

The interlingual dictionaries had a far greater stock of English words than were to be found in the earliest all-English dictionaries, and the compilers of the English dictionaries, strangely enough, never took full advantage of these sources. It may be surmised, however, that people in general sometimes consulted the interlingual dictionaries for the English vocabulary. The anonymous author of *The Arte of English Poesie,* thought to be George Puttenham, wrote, in 1589, concerning the adoption of southern speech as the standard:

> herein we are already ruled by th' English Dictionaries and other bookes written by learned men, and therefore is needeth none other direction in that behalfe.

The mainstream of English lexicography is the word list explained in English. The first known English–English glossary grew out of the desire of the supporters of the Reformation that even the most humble Englishman should be able to understand the Scriptures. William Tyndale, when he printed the Pentateuch on the Continent in 1530, included "A table expoundinge certeyne wordes." The following entries are typical:

> Albe, a longe garment of white lynen.
> Boothe, an housse made of bowes.
> Brestlappe or brestllappe, is soche a flappe as thou seist in the brest or a cope.
> Consecrate, to apoynte a thinge to holy uses.
> Dedicate, purifie or sanctifie.
> Firmament: the skyes.
> Slyme was . . . a fatteneese that osed out of the erth lyke unto tarre/And thou mayst call it cement/if thou wilt.
> Tabernacle, an house made tentwise, or as a pauelion.
> Vapor/a dewymiste/as the smoke of a sethynge pott.

Spelling reformers long had a deep interest in producing English dictionaries. In 1569 one such reformer, John Hart, lamented that the "disorders and confusions" of spelling were so great that "there can be made no perfite Dictionarie nor Grammer." But a few years later the phonetician William Bullokar promised to produce such a work and stated, "A dictionary and grammar may stay our speech in a perfect use for euer."

The schoolmasters also had a strong interest in the development of dictionaries. In 1582 Richard Mulcaster, of the Merchant Taylors' school and later of St. Paul's, expressed the wish that some learned and laborious man "wold gather all the words which we vse in our English tung," and in his book commonly referred to as *The Elementarie* he listed about 8,000 words, without definitions, in a section called "The Generall Table." Another schoolmaster, Edmund Coote, of Bury St. Edmund's, in 1596 brought out *The Englishe Scholemaister, teachinge all his schollars of what age soever the most easie short & perfect order of distinct readinge & true writinge our Englishe tonge,* with a table that consisted of about 1,400 words, sorted out by different typefaces on the basis of etymology. This is important, because what is known as the "first" English dictionary, eight years later, was merely an adaptation and enlargement of Coote's table.

FROM 1604 TO 1828

First purely English dictionary

In 1604 at London appeared the first purely English dictionary to be issued as a separate work, entitled *A Table Alphabeticall, conteyning and teaching the true writing and understanding of hard usuall English wordes, borrowed from the Hebrew, Greeke, Latine,* or *French &c.,* by Robert Cawdrey, who had been a schoolmaster at Oakham, Rutland, about 1580, and in 1604 was living at Coventry. He had the collaboration of his son Thomas, a schoolmaster in London. This work contained about 3,000 words but was so dependent upon three sources that it can rightly be called a plagiarism. The basic outline was taken over from Coote's work of 1596, with 87 percent of his word list adopted. Further material was taken from the Latin–English dictionary by Thomas Thomas, *Dictionarium linguae Latinae et Anglicanae* (1588). But the third source is most remarkable. In 1599 a Dutchman known only as A.M. translated from Latin into English a famous medical work by Oswald Gabelkhouer, *The Boock of Physicke,* published at Dort, in the Netherlands. As he had been away from England for many years and had forgotten much of his English, A.M. sometimes merely put English endings on Latin words. When friends told him that Englishmen would not understand them, he compiled a list of them, explained by a simpler synonym, and put it at the end of the book. Samples are: "Puluerisated, reade beaten; Frigifye, reade coole; Madefye, reade dipp; Calefye, reade heat; Circumligate, reade binde; Ebulliated, read boyled." Thus, the fumblings of a Dutchman who knew little English (in fact, his errata) were poured into Cawdrey's word list. But other editions of Cawdrey were called for—a second in 1609, a third in 1613, and a fourth in 1617.

The next dictionary, by John Bullokar, *An English Expositor,* is first heard of on May 25, 1610, when it was entered in the Stationers' Register (which established the printer's right to it), but it was not printed until six years later. Bullokar introduced many archaisms, marked with a star ("onely used of some ancient writers, and now growne out of use"), such as "aye," "eld," "enewed," "fremd," "gab," and "glee." The work had 14 editions, the last as late as 1731.

Still in the tradition of hard words was the next work, in 1623, by Henry Cockeram, the first to have the word dictionary in its title: *The English Dictionarie: or, an Interpreter of hard English Words.* It added many words that have never appeared anywhere else—adpugne, adstupiate, bulbitate, catillate, fraxate, nixious, prodigity, vitulate, and so on. Much fuller than its predecessors was Thomas Blount's work of 1656, *Glossographia: or, a dictionary Interpreting all such hard words . . . as are now used in our refined English tongue.* He made an important forward step in lexicographical method by collecting words from his own reading that had given him trouble; and he often cited the source. Much of Blount's material was appropriated two years later by Edward Phillips, a nephew of the

poet Milton, for a work called *The New World of English Words*, and Blount castigated him bitterly.

Kersey's *New English Dictionary*

Thus far, the English lexicographers had all been men who made dictionaries in their leisure time or as an avocation, but in 1702 appeared a work by the first professional lexicographer, John Kersey the Younger. This work, *A New English Dictionary*, incorporated much from the tradition of spelling books and discarded most of the fantastic words that had beguiled earlier lexicographers. As a result, it served the reasonable needs of ordinary users of the language. Kersey later produced some bigger works, but all of these were superseded in the 1720s, when Nathan Bailey, a schoolmaster in Stepney, issued several innovative works. In 1721 he produced *An universal etymological English Dictionary*, which for the rest of the century was more popular even than Dr. Johnson's. A supplement in 1727 was the first dictionary to mark accents for pronunciation. Bailey's imposing *Dictionarium Britannicum* of 1730 was used by Samuel Johnson as a repository during the compilation of the monumental dictionary of 1755.

Many literary men felt the inadequacy of English dictionaries, particularly in view of the continental examples. The Accademia della Crusca, of Florence, founded in 1582, brought out its *Vocabolario* at Venice in 1612, filled with copious quotations from Italian literature. The Académie Française produced its dictionary in 1694, but two other French dictionaries were actually more scholarly—that of Cèsar-Pierre Richelet in 1680 and that of Antoine Furetière in 1690. In Spain the Royal Spanish Academy (Real Academia Española), founded in 1713, produced its *Diccionario de la lengua Castellana*, 1726–39, in six thick volumes. The foundation work of German lexicography, by Johann Leonhard Frisch, *Teutsch-Lateinisches Wörterbuch*, in 1741, freely incorporated quotations in German. The Russian Academy of Arts (St. Petersburg) published the first edition of its dictionary somewhat later, from 1789 to 1794. Both the French and the Russian academies arranged the first editions of their dictionaries in etymological order but changed to alphabetical order in the second editions.

Samuel Johnson's *Plan*

In England, in 1707, the antiquary Humphrey Wanley set down in a list of "good books wanted," which he hoped the Society of Antiquaries would undertake: "A dictionary for fixing the English language, as the French and Italian." A number of noted authors made plans to fulfill this aim (Joseph Addison, Ambrose Philips, Alexander Pope, and others), but it remained for a promising poet and critic, Samuel Johnson, to bring such a project to fulfillment. Five leading booksellers of London banded together to support his undertaking, and a contract was signed on June 18, 1746. Next year Johnson's *Plan* was printed, a prospectus of 34 pages, consisting of a discussion of language that can still be read as a masterpiece in its judicious consideration of linguistic problems.

With the aid of six amanuenses to copy quotations, Johnson read widely in the literature up to his time and gathered the central word-stock of the English language. He included about 43,500 words (a few more than the number in Bailey), but they were much better selected and represented the keen judgment of a man of letters. He was sympathetic to the desire of that age to "fix" the language, but he realized as he went ahead that "language is the work of man, of a being from whom permanence and stability cannot be derived." At most, he felt that he could curb "the lust for innovation."

The chief glory of Johnson's dictionary was its 118,000 illustrative quotations. No doubt some of these were included for their beauty, but mostly they served as the basis for his sense discriminations. No previous lexicographer had the temerity to divide the verb "take," transitive, into 113 senses and the intransitive into 21 more. The definitions often have a quaint ring to modern readers because the science of the age was either not well developed or was not available to him. But mostly the definitions show a sturdy common sense, except when Johnson used long words sportively. His etymologies reflect the state of philology in his age. Usually they were an improvement on those of his predecessors, because he had as a guide the *Etymologicum Anglicanum* of Franciscus Junius, as edited by Edward Lye, which became available in 1743 and which provided guidance for the important Germanic element of the language.

Four editions of the *Dictionary* were issued during Dr. Johnson's lifetime; in particular the fourth, in 1773, received much personal care in revision. The *Dictionary* retained its supremacy for many decades and received lavish, although not universal, praise; some would-be rivals were bitter in criticism. A widely heralded work of the 1780s and 1790s was the projected dictionary of Herbert Croft, in a manuscript of 200 quarto volumes, that was to be called the *Oxford English Dictionary*. Croft was, however, unable to get it into print.

Pronouncing dictionaries

The practice of marking word stress was taken over from the spelling books by Bailey in his *Dictionary* of 1727, but a full-fledged pronouncing dictionary was not produced until 1757, by James Buchanan; his was followed by those of William Kenrick (1773), William Perry (1775), Thomas Sheridan (1780), and John Walker (1791), whose decisions were regarded as authoritative, especially in the United States.

The attention to dictionaries was thoroughly established in U.S. schools in the 18th century. Benjamin Franklin, in 1751, in his pamphlet "Idea of the English School," said, "Each boy should have an English dictionary to help him over difficulties." The master of an English grammar school in New York in 1771, Hugh Hughes, announced: "Every one of this Class will have Johnson's Dictionary

Oa'tmeal. *n. ſ.* [*oat* and *meal.*] Flower made by grinding oats.

Oatmeal and butter, outwardly applied, dry the ſcab on the head. *Arbuthnot on Aliment.*

Our neighbours tell me oft, in joking talk,
Of aſhes, leather, *oatmeal*, bran, and chalk. *Gay.*

Oa'tmeal. *n. ſ.* An herb. *Ainſworth.*

Oats. *n. ſ.* [æten, Saxon.] A grain, which in England is generally given to horſes, but in Scotland ſupports the people.

It is of the graſs leaved tribe; the flowers have no petals, and are diſpoſed in a looſe panicle: the grain is eatable. The meal makes tolerable good bread. *Miller.*

The *oats* have eaten the horſes. *Shakeſpeare.*

It is bare mechaniſm, no otherwiſe produced than the turning of a wild *oatbeard*, by the infinuation of the particles of moiſture. *Locke.*

For your lean cattle, fodder them with barley ſtraw firſt, and the *oat* ſtraw laſt. *Mortimer's Huſbandry.*

His horſe's allowance of *oats* and beans, was greater than the journey required. *Swift.*

Oa'tthistle. *n. ſ.* [*oat* and *thiſtle.*] An herb. *Ainſ.*

The definition of "Oats" (top) by Samuel Johnson in his *Dictionary* of 1755 exemplifies his prejudice against the Scots and shows his divergence from his source, Nathan Bailey (bottom), who interspersed idiomatic examples throughout his entries (1736).

By courtesy of the Newberry Library, Chicago

Oars, [oþan. *Sax* ara *Su*] a boat for carrying paſſengers, with two men to row it; alſo inſtruments wherewith boats are row'd.

To have an Oar in every Man's Boat.

That is, to meddle with every man's concerns.

Oats [of æten or eran. *Sax.* to eat] a grain, food for horſes.

To ſow one's wild Oats.

That is to play one's youthful pranks.

Oat *Thiſtle*, an herb.

Oa'ten, of or pertaining to oats

Oath [aÐ, *Sax.* Eþ, *Dan* and *Su.* Eder, *Da.* Epv, G.] a ſwearing, or confirming a thing by ſwearing.

Oath [in a legal ſenſe] a ſolemn action, whereby God is called to witneſs the truth of an affirmation, given before one or more perſons impowered to receive the ſame.

Oat-meal [of æten and mealepe, *Sax.*] meal or flour made of oats.

in Octavo." These were imported from England, because the earliest dictionary printed in the U.S. was in 1788, when Isaiah Thomas of Worcester, Massachusetts, issued an edition of Perry's *Royal Standard English Dictionary*. The first dictionary compiled in America was *A School Dictionary* by Samuel Johnson, Jr. (not a pen name), printed in New Haven, Connecticut, in 1798. Another, by Caleb Alexander, was called *The Columbian Dictionary of the English Language* (1800) and on the title page claimed that "many new words, peculiar to the United States," were inserted. It received abuse from critics who were not yet ready for the inclusion of American words.

In spite of such attitudes, Noah Webster, already well known for his spelling books and political essays, embarked on a program of compiling three dictionaries of different sizes that included Americanisms. In his announcement on June 4, 1800, he entitled the largest one *A Dictionary of the American Language*. He brought out his small dictionary for schools, the *Compendious*, in 1806 but then engaged in a long course of research into the relation of languages, in order to strengthen his etymologies. At last, in 1828, at the age of 70, he published his master work, in two thick volumes, with the title *An American Dictionary of the English Language*. His change of title reflects his growing conservatism and his recognition of the fundamental unity of the English language. His selection of the word list and his well-phrased definitions made his work superior to previous works, although he did not give illustrative quotations but merely cited the names of authors. The dictionary's worth was recognized, although Webster himself was always at the centre of a whirlpool of controversy.

SINCE 1828

New trends in dictionary making

It was Noah Webster's misfortune to be superseded in his philology in the very decade that his masterpiece came out. He had spent many years in compiling a laborious "Synopsis" of 20 languages, but he lacked an awareness of the systematic relationships in the Indo-European family of languages. Germanic scholars such as Jacob Grimm, Franz Bopp, and Rasmus Rask had developed a rigorous science of "comparative philology," and a new era of dictionary making was called for. Even as early as 1812 Franz Passow had published an essay in which he set forth the canons of a new lexicography, stressing the importance of the use of quotations arranged chronologically in order to exhibit the history of each word. The brothers Jacob and Wilhelm Grimm developed these theories in their preparations for the *Deutsches Wörterbuch* in 1838. The first part of it was printed in 1852, but the end was not reached until more than a century later, in 1960. French scholarship was worthily represented by Maximilien-Paul-Émile Littré, who began working on his *Dictionnaire de la langue française* in 1844, but, with interruptions of the Revolution of 1848 and his philosophical studies, he did not complete it until 1873.

Among scholars in England the historical outlook took an important step forward in 1808 in the work of John Jamieson on the language of Scotland. Because he did not need to consider the "classical purity" of the language, he included quotations of humble origin; in his *Etymological Dictionary of the Scottish Language*, his use of "mean" sources marked a turning point in the history of lexicography. Even as late as 1835 the critic Richard Garnett said that "the only good English dictionary we possess is Dr. Jamieson's Scottish one." Another collector, James Jermyn, showed by his publications between 1815 and 1848 that he had the largest body of quotations assembled before that of *The Oxford English Dictionary*. Charles Richardson was also an industrious collector, presenting his dictionary, from 1818 on, distributed alphabetically throughout the *Encyclopaedia Metropolitana* (vol. 14 to 25) and then reissued as a separate work in 1835–37. Richardson was a disciple of the benighted John Horne Tooke, whose 18th-century theories long held back the development of philology in England. Richardson excoriated Noah Webster for ignoring "the learned elders of lexicography" such as John Minsheu (whose *Guide into the Tongues* appeared in 1617), Gerhard Johannes Vossius (who published his *Etymologicum linguae Latinae* in 1662), and Franciscus Junius (*Etymologicum Anglicanum*, written before 1677). Richardson did collect a rich body of illustrative quotations, sometimes letting them show the meaning without a definition, but his work was largely a monument of misguided industry that met with the neglect it deserved.

The beginnings of the *OED*

Scholars more and more felt the need for a full historical dictionary that would display the English language in accordance with the most rigorous scientific principles of lexicography. The Philological Society, founded in 1842, established an Unregistered Words Committee," but, upon hearing two papers by Richard Chenevix Trench in 1857—"On Some Deficiencies in Our English Dictionaries"—the society changed its plan to the making of *A New English Dictionary on Historical Principles*. Forward steps were taken under two editors, Herbert Coleridge and Frederick James Furnivall, until, in 1879, James Augustus Henry Murray, a Scot known for his brilliance in philology, was engaged as editor. A small army of voluntary readers were inspirited to contribute quotation slips, which reached the number of 5,000,000 in 1898, and no doubt 1,000,000 were added after that. Only 1,827,306 of them were used in print. The copy started going to the printer in 1882; Part I was finished in 1884. Later, three other editors were added, each editing independently with his own staff—Henry Bradley, from the north of England, in 1888, William Alexander Craigie, another Scot, in 1901, and Charles Talbut Onions, the only "Southerner," in 1914. So painstaking was the work that it was not finished until 1928, in over 15,500 pages with three long columns each. An extraordinary high standard was maintained throughout. The work was reprinted, with a supplement, in 12 volumes in 1933 with the title *The Oxford English Dictionary*, and as the *OED* it has been known ever since.

In the United States, lexicographical activity has been unceasing since 1828. In the middle years of the 19th century, a "war of the dictionaries" was carried on between the supporters of Noah Webster and those of his rival, Joseph Emerson Worcester. To a large extent, this was a competition between publishers who wished to preempt the market in the lower schools, but literary people took sides on the basis of other issues. In particular, the contentious Noah Webster had gained a reputation as a reformer of spelling and a champion of American innovations, while the quiet Worcester followed traditions.

In 1846 Worcester brought out an important new work, *A Universal and Critical Dictionary of the English Language*, which included many neologisms of the time, and in the next year Webster's son-in-law, Chauncey Allen Goodrich, edited an improved *American Dictionary* of the deceased Webster. In this edition the Webster interests were taken over by an aggressive publishing firm, the G. & C. Merriam Company. Their agents were very active in the "war of the dictionaries" and sometimes secured an order, by decree of a state legislature, for their book to be placed in every schoolhouse of the state. Worcester's climactic edition of 1860, *A Dictionary of the English Language*, gave him the edge in the "war," and James Russell Lowell declared: "From this long conflict Dr. Worcester has unquestionably come off victorious." The Merriams, however, brought out their answer in 1864, popularly called "the unabridged," with etymologies supplied by a famous German scholar, Karl August Friedrich Mahn. Thereafter, the Worcester series received no major re-editing, and its faltering publishers allowed it to pass into history.

The Century Dictionary

One of the best English dictionaries ever compiled was issued in 24 parts from 1889 to 1891 as *The Century Dictionary*, edited by William Dwight Whitney. It contained much encyclopaedic material but bears comparison even with the *OED*. Isaac Kauffman Funk, in 1893, brought out *A Standard Dictionary of the English Language*, its chief innovation being the giving of definitions in the order of their importance, not the historical order. Thus, at the turn of the new century, the U.S. had four reputable dictionaries—Webster's, Worcester's (already becoming moribund), the *Century*, and Funk's *Standard*. England was also well served by many (the original dates given here)—John Ogilvie (1850), P. Austin Nuttall (1855), Robert Gor-

don Latham (1866, re-editing Todd's Johnson of 1818), Robert Hunter (1879), and Charles Annandale (1882).

Kinds of dictionaries

GENERAL-PURPOSE DICTIONARIES

Although one may speak of a "general-purpose" dictionary, it must be realized that every dictionary is compiled with a particular set of users in mind. In turn, the public has come to expect certain conventional features (see below *Features and problems*), and a publisher departs from the conventions at his peril. One of the chief demands is that a dictionary should be "authoritative," but the word authoritative is ambiguous. It can refer to the quality of scholarship, the employment of the soundest information available, or it can describe a prescriptive demand for compliance to particular standards. Many people ask for arbitrary decisions in usage choices, but most linguists feel that when a dictionary goes beyond its function of recording accurate information on the state of the language it becomes a bad dictionary.

Most people know dictionaries in the abridged sizes, commonly called "desk" or "college-size" dictionaries. Such abridgments go back to the 18th century. Their form had become stultified until, in the 1930s, Edward Lee Thorndike produced a series for schools (*Beginning, Junior,* and *Senior*). His dictionaries were not "museums" but tools that encouraged schoolchildren to learn about language. He drew upon his word counts and his "semantic counts" to determine inclusions. The new mode was carried on to the college level by Clarence L. Barnhart in *The American College Dictionary* (*ACD*), in 1947, and in the later college-size works that were revised to meet that competition—the Merriam-Webster *Seventh New Collegiate* (1963), the *Standard College Dictionary* (1963), and *Webster's New World Dictionary* (1953, and second edition 1970). An especially valuable addition was *The Random House Dictionary* (1966), edited by Jess Stein in a middle size called "the unabridged" and by Laurence Urdang in a smaller size (1968). The Merriam-Webster *Collegiate* series was subsequently extended to eighth (1973), ninth (1983), 10th (1993), and 11th (2003) editions. (The G. & C. Merriam Co. [now Merriam-Webster, Inc.] was acquired by Encyclopædia Britannica, Inc., in 1964.)

The Merriam-Webster *New International* of 1909 had a serene, uncluttered air that suited a simpler age. The second edition, completely reedited, appeared in 1934, and it, in turn, was superseded in 1961 by the *Third New International*, edited by Philip Babcock Gove. Because its competitors of similar size have not been kept up to date, it stands alone among American dictionaries in giving a full report on the lexicon of present-day English. Unfortunately, the publicity before publication emphasized the quotations from ephemeral writers such as Polly Adler, Ethel Merman, and Mickey Spillane and the statement about "ain't" as "used orally in most parts of the U.S. by many cultivated speakers." Such reports aroused a storm of denunciation in newspapers and magazines by writers who, others asserted, revealed a shocking ignorance of the nature of language. The comments were collected in a "casebook" entitled *Dictionaries and That Dictionary*, edited by James H. Sledd and Wilma R. Ebbitt (1962).

The *Third New International*

In 1969 came *The American Heritage Dictionary*, edited by William Morris, who was known for his valuable small dictionary *Words* (1947). The *American Heritage* was designed to take advantage of the reaction against the Merriam-Webster *Third*. A "usage panel" of 104 members, chosen mostly from the conservative "literary establishment," provided material for a set of "usage notes." Their pronouncements, found by scholars to be inconsistent, were supposed to provide "the essential dimension of guidance," as the editor put it, "in these permissive times." The etymological material was superior to that in comparable dictionaries.

In England, Henry Cecil Wyld produced his *Universal Dictionary of the English Language* (1932), admirable in every way except for its elitism. The smaller-sized dictionaries of the Oxford University Press deserved their wide circulation.

SCHOLARLY DICTIONARIES

Beyond the dictionaries intended for practical use are the scholarly dictionaries, with the scientific goal of completeness and rigour in their chosen area. Probably the most scholarly dictionary in the world is the *Thesaurus Linguae Latinae*, edited in Germany and Austria. Its main collections were made from 1883 to 1900, when publication began, but by 2004 its publication had reached only the letter *P*. A number of countries have had "national dictionaries" under way—projects that often take many decades. Two of these have already been mentioned—the Grimm dictionary for German (a revised and expanded edition begun in 1965) and the Littré for French (reedited 1956–58); but, in addition, there are the *Woordenboek der Nederlandsche taal* (1882–1998) for Dutch, and now available online; the *Ordbok öfver svenska språket* (begun 1898) for Swedish; the *Slovar sovremennogo russkogo literaturnogo yazyka* ("Dictionary of Modern Literary Russian," 1950–65); the *Norsk Ordbok* for Norwegian (1966– , 12th and last volume projected for 2014); and the *Ordbog over det danske Sprog* (1995) for Danish. Of outstanding scholarship are *An Encyclopaedic Dictionary of Sanskrit on Historical Principles* being prepared at Pune (Poona), India (begun 1976), and *The Historical Dictionary of the Hebrew Language*, in progress in Jerusalem. The most ambitious project of all is the *Trésor de la langue française*. In the 1960s more than 250,000,000 word examples were collected, using the latest techniques of computerization. Publication began in 1971, but after two volumes the scope of the work was scaled back from 60 (planned) volumes to about 15.

Thesaurus Linguae Latinae

The *Oxford English Dictionary* remains the supreme completed achievement in all lexicography. After its completion in 1928, the remaining quotations, both used and unused, were divided up for use in a set of "period dictionaries." The prime mover of this plan, Sir William Craigie, undertook *A Dictionary of the Older Scottish Tongue* himself, covering the period from the 14th to the 17th century in Scottish speech. Enough material was amassed under his direction so that editing could begin in 1925 (publication, however, did not begin until 1931), and before his death in 1957 he arranged that it should be carried on at the University of Edinburgh. It was completed in 2003. The work on the older period spurred the establishment of a project on modern Scots, which got under way in 1925, called *The Scottish National Dictionary* (published 1931–76), giving historical quotations after the year 1700.

Period dictionaries for English

In the mainstream of English, a period dictionary for Old English (before 1100) was planned for many decades by a dictionary committee of the Modern Language Association of America (Old English section) and finally got under way in the late 1960s at the Pontifical Institute of Mediaeval Studies at the University of Toronto. The *Dictionary of Old English* is based on a combining of computerized concordances of bodies of Old English literature. A *Middle English Dictionary*, covering the period 1100 to 1475, was completed in 2001. For the period 1475 to 1700, an *Early Modern English Dictionary* has not fared as well. It got under way in 1928 at the University of Michigan, and more than 3,000,000 quotation slips were amassed, but the work could not be continued in the decade of the Great Depression, and only in the mid-1960s was it revived. The *OED* supplement of 1933 was itself supplemented in 4 volumes (1972–86). A second edition of the OED was published in 20 volumes in 1989, an expanded integration of the original 12-volume set and the 4-volume set into one sequence. In 1992 the second edition was released on CD-ROM. Three volumes of Additions to the Second Edition were published in print in 1993 and 1997, and the online version was launched in 2000.

Craigie, in 1925, proposed a dictionary of American English. Support was found for the project, and he transferred from Oxford University to the University of Chicago in order to become its editor. The aim of the work, he wrote, was that of "exhibiting clearly those features by which the English of the American colonies and the United States is distinguished from that of England and the rest of the

English-speaking world." Thus, not only specific Americanisms were dealt with but words that were important in the natural history and cultural history of the New World. After a 10-year period of collecting, publication began in 1936 under the title *A Dictionary of American English on Historical Principles,* and the 20 parts (four volumes) were completed in 1944. This was followed in 1951 by a work that limited itself to Americanisms only—*A Dictionary of Americanisms,* edited by Mitford M. Mathews.

The English language, as it has spread widely over the world, has come to consist of a group of coordinate branches, each expressing the needs of its speakers in communication; further scholarly dictionaries are needed to record the particular characteristics of each branch. Both Canada and Jamaica were treated in 1967—*A Dictionary of Canadianisms on Historical Principles,* Walter Spencer Avis, editor in chief, and *Dictionary of Jamaican English,* edited by Frederic G. Cassidy and R.B. LePage. A historical dictionary of South African English is under way at Rhodes University, Grahamstown, South Africa, edited by William Branford, and some day full dictionaries must be compiled for Australian English, New Zealand English, and so on. Such dictionaries are valuable in displaying the intimate interrelations of the language to the culture of which it is a part.

SPECIALIZED DICTIONARIES

Earliest English etymological dictionary

Specialized dictionaries are overwhelming in their variety and their diversity. Each area of lexical study, such as etymology, pronunciation, and usage, can have a dictionary of its own. The earliest important dictionary of etymology for English was Stephen Skinner's *Etymologicon Linguae Anglicanae* of 1671, in Latin, with a strong bias for finding a classical origin for every English word. In the 18th century, a number of dictionaries were published that traced most English words to Celtic sources, because the authors did not realize that the words had been borrowed into Celtic rather than the other way around. With the rise of a soundly based philology by the middle of the 19th century, a scientific etymological dictionary could be compiled, and this was provided in 1879 by Walter William Skeat. It has been kept in print in re-editions ever since but was superseded in 1966 by *The Oxford Dictionary of English Etymology,* by Charles Talbut Onions, who had worked many decades on it until his death. Valuable in its particular restricted area is J.F. Bense's *Dictionary of the Low-Dutch Element in the English Vocabulary* (1926–39).

Two works are especially useful in showing the relation between languages descended from the ancestral Indo-European language—Carl Darling Buck's *Dictionary of Selected Synonyms in the Principal Indo-European Languages* (1949) and Julius Pokorny's *Indogermanisches etymologisches Wörterbuch* (1959). The Indo-European roots are well displayed in the summary by Calvert Watkins, published as an appendix to *The American Heritage Dictionary* mentioned earlier. Interrelations are also dealt with by Eric Partridge in his *Origins* (1958).

The pronouncing dictionary, a type handed down from the 18th century, is best known in the present day by two examples, one in England and one in America. That of Daniel Jones, *An English Pronouncing Dictionary,* represents what is "most usually heard in everyday speech in the families of Southern English persons whose men-folk have been educated at the great public boarding-schools." Although he called this the Received Pronunciation (RP), he had no intention of imposing it on the English-speaking world. It originally appeared in 1917 and was repeatedly revised during the author's long life. Also strictly descriptive was a similar U.S. work by John S. Kenyon and Thomas A. Knott, *A Pronouncing Dictionary of American English,* published in 1944 and never revised but still valuable for its record of the practices of its time.

The "conceptual dictionary," in which words are arranged in groups by their meaning, had its first important exponent in Bishop John Wilkins, whose *Essay towards a Real Character and a Philosophical Language* was published in 1668. A plan of this sort was carried out by Peter Marc Roget with his *Thesaurus,* published in 1852 and many times reprinted and re-edited. Although philosophically oriented, Roget's work has served the practical purpose of another genre, the dictionary of synonyms.

Dictionaries of usage

The dictionaries of usage record information about the choices that a speaker must make among rival forms. In origin, they developed from the lists of errors that were popular in the 18th century. Many of them are still strongly puristic in tendency, supporting the urge for "standardizing" the language. The work with the most loyal following is Henry Watson Fowler's *Dictionary of Modern English Usage* (1926), ably re-edited in 1965 by Sir Ernest Gowers. It represents the good taste of a sensitive, urbane litterateur. It has many devotees in the U.S. and also a number of competitors. Among the latter, the most competently done is *A Dictionary of Contemporary American Usage* (1957), by Bergen Evans and Cornelia Evans. Usually the dictionaries of usage have reflected the idiosyncrasies of the compilers; but, from the 1920s to the 1960s, a body of studies by scholars emphasized an objective survey of what is in actual use, and these were drawn upon by Margaret M. Bryant for her book *Current American Usage* (1962). A small corner of the field of usage is dealt with by Eric Partridge in *A Dictionary of Clichés* (1940).

The regional variation of language has yielded dialect dictionaries in all the major languages of the world. In England, after John Ray's issuance of his first glossary of dialect words in 1674, much collecting was done, especially in the 19th century under the auspices of the English Dialect Society. This collecting culminated in the splendid *English Dialect Dictionary* of Joseph Wright in six volumes (1898–1905). American regional speech was collected from 1774 onward; John Pickering first put a glossary of Americanisms into a separate book in 1816. The American Dialect Society, founded in 1889, made extensive collections, with plans for a dictionary, but this came to fruition only in 1965, when Frederic G. Cassidy embarked on *A Dictionary of American Regional English* (known as *DARE*).

The many "functional varieties" of English also have their dictionaries. Slang and cant in particular have been collected in England since 1565, but the first important work was published in 1785, by Capt. Francis Grose, *A Classical Dictionary of the Vulgar Tongue,* reflecting well the low life of the 18th century. In 1859 John Camden Hotten published the 19th-century material, but a full historical, scholarly survey was presented by John Stephen Farmer and W.E. Henley in their *Slang and Its Analogues,* in seven volumes, 1890–1904, with a revised first volume in 1909 (all reprinted in 1971). For the present century, the dictionaries of Eric Partridge are valuable. Slang in the United States is so rich and varied that collectors have as yet only scratched the surface, but the work by Harold Wentworth and Stuart B. Flexner, *Dictionary of American Slang* (1960), can be consulted. The argot of the underworld has been treated in many studies by David W. Maurer.

Bilingual dictionaries

Of all specialized dictionaries, the bilingual group are the most serviceable and frequently used. With the rise of the vernacular languages during the Renaissance, translating to and from Latin had great importance. The Welshman in England was provided with a bilingual dictionary as early as 1547, by William Salesbury. Scholars in their analyses of language, as well as practical people for everyday needs, are anxious to have bilingual dictionaries. Even the most exotic and remote languages have been tackled, often by religious missionaries with the motive of translating the Bible. The finding of exact equivalents is more difficult than is commonly realized, because every language slices up the world in its own particular way.

Dictionaries dealing with special areas of vocabulary are so overwhelming in number that they can merely be alluded to here. In English, the earliest was a glossary of law terms published in 1527 by John Rastell. His purpose, he said, was "to expown certeyn obscure & derke termys concernynge the lawes of thys realme." The dictionaries of technical terms in many fields often have the purpose of standardizing the terminology; this normative aim is especially important in newly developing countries where the language has not yet become accommodated to modern

technological needs. In some fields, such as philosophy, religion, or linguistics, the terminology is closely tied to a particular school of thought or the individual system of one writer, and, consequently, a lexicographer is obliged to say, "according to Kant," "in the usage of Christian Science," "as used by Bloomfield," and so on.

Features and problems

ESTABLISHMENT OF THE WORD LIST

Problems in selecting a word list

The goal of the big dictionaries is to make a complete inventory of a language, recording every word that can be found. The obsolete and archaic words must be included from the earlier stages of the language and even the words attested to only once (nonce words). In a language with a large literature, many "uncollected words" are likely to remain, lurking in out-of-the-way sources. The *OED* caught many personal coinages, but not "head-over-heelishness" (1882), "odditude" (1860), "pigstyosity" (1869), "whitechokerism" (1866), and other graceless jocularities. Also, the so-called latent words are a problem, when a lexicographer knows that a derivative word probably has been used, but he has no evidence for it. The *OED* had three quotations for "kindheartedness" but none for "kindheartedly," which any speaker of English would feel free to use. Some "ghost words" have arisen from the misreading of manuscripts and from misprints, and the lexicographer attempts to cast these out.

Various large blocks of words have a questionable status. Both geographic names and biographical entries are selectively included in some dictionaries but are really encyclopaedic. More than 2,000,000 insects have been identified and named by entomologists, while names of chemical compounds and drugs may be almost as numerous. Trade names and proprietary names may number in the hundreds of thousands. Vogue suffixes like "-ism," "-ology," "-scope," or "-wise" are used by some with the freedom of a grammatical construction. These millions are beyond what any dictionary can be expected to include.

For the smaller-sized dictionaries, the editors attempt to choose the words that are likely to be looked up. They comb the scholarly works carefully and supplement them from files that they may have collected. They may decide to put derivative words at the end of entries as "runons" or to have all words strictly as separate alphabetical entries. The size is ultimately decided by the commercial consideration of how much can be put into a work that can be sold for a reasonable price and held readily in the hand. (Bulk also influences the size of the word list for unabridged dictionaries.)

The establishment of a word list involves many difficult technical problems. Linguists tend to use the terms morpheme, free form, bound form, lexeme, and so on, inasmuch as "word" is a popular term not suited to technical use. A safe compromise is to use "lexical unit." This term allows the inclusion of set phrases (established groups) and idioms. Words having different etymological sources must be considered as different words. Thus "calf" in the sense of the young of a bovine animal came from Common Germanic, whereas "calf" for the fleshy back of the lower part of the leg came from Old Norse, perhaps from a Celtic source. A more difficult problem is found when a word entered the language at different points—such as "cookie," from the Dutch *koekje* "little cake," recorded in Scottish in 1701 in the form *cuckie*, then independently taken from the Dutch of the Hudson Valley in the form *cookie* in 1703, and perhaps independently taken into South African English from Afrikaans in the mid-19th century.

SPELLING

British and American spelling

Dictionaries have probably played an important role in establishing the conventions of English spelling. Dr. Johnson has received much credit for this, though he differed very little from his predecessors. He used the spelling "smoak" in the early part of his dictionary, but when he came to the entry itself, he changed it to "smoke," and this has prevailed. Noah Webster introduced some simplifications that have become accepted in American English. American dictionaries usually label the distinctive British spellings, such as "centre" and its class, "honour" and its class, "connexion," "gaol," "kerb," "tyre," "waggon," and a few others.

The desire for uniformity is so great that popular variants are not welcomed; the very common "alright" is not yet approved, nor is the widespread "miniscule" for "minuscule." The *OED* is exceptional in listing the early variant spellings, showing that a common word like "good" has been spelled in 13 different ways, with seven more from Scottish usage. When the spelling reform movement was at its height, from the 1880s to about 1910, the dictionaries included the new forms, but in recent years these have been expunged. The graphic dress of the language is now so sacrosanct that dictionaries are used as authoritarian "style manuals" in matters of spelling, hyphenation, and syllabification.

PRONUNCIATION

Dictionaries are more responsive to usage in the matter of pronunciation than they are in spelling. It is claimed that in the 19th century the Merriam-Webster dictionaries foisted a New England pronunciation on the United States, but in recent years many regional variations have been recorded. *Webster's Third New International* (1961) went to surprising lengths in its variants; perhaps its record is in giving 132 different ways of pronouncing "a fortiori."

The former practice of giving pronunciations as if the words were pronounced in isolation in a formal manner represented an artificiality that distorted language in use; recent dictionaries have marked pronunciation as it appears in continuous discourse. Furthermore, there has been a trend toward what has been called "democratization." In the word "government," for instance, it is recognized that many people do not pronounce an *n*, and some people actually say something like "gubb-munt." There is a constant battle between traditional spoken forms and spelling pronunciations.

Systems for indicating sounds

Since the alphabet is notoriously inadequate for recording the sounds of English, dictionaries are forced to adopt additional symbols. A system of using numerals over vowels was handed down from the 18th century, but that gave way to the diacritic markings of the Merriam-Webster series. The rise of the International Phonetic Alphabet (IPA) has offered another possibility, but the general public as yet finds it abstruse. Even more detailed symbols are needed in linguistic atlases and phonetic research. With considerable courage, Clarence L. Barnhart introduced the symbol schwa (ə) into *The American College Dictionary* (1947) for the neutral midcentral vowel, as at the beginning and end of "America," and the symbol has now become widely accepted. Although some systems are clumsier than others, the key does not matter much if it is applied consistently.

ETYMOLOGY

The supplying of etymologies involves such difficult decisions for a lexicographer as whether words should be carried back into prehistory by means of reconstructed forms or the degree to which speculation should be permitted. A U.S. Romance scholar, Yakov Malkiel, has presented the notion that words follow "trajectories"—by finding certain points in the history of a word, one can link up the developments in form and meaning. The austere treatment of some words consists in saying "derivation unknown," and yet this sometimes causes interesting possibilities to be ignored.

Native stock and loanwords

A fundamental distinction is made in word history between the "native stock" and the "loanwords." There have been so many borrowings into English that the language has been called "hypertrophied." The traditional view is to regard the borrowings as a source of "richness." A historical dictionary does its best to ascertain the date at which a word was adopted from another language, but the word may have to go through a period of probation. Murray, the editor of the *OED*, listed four stages of word "citizenship": the casual, the alien, the denizen, and the natural. The casuals may not be part of the language, as they appear only in travel writings and accounts of foreign

countries, but a lexicographer must collect citations for them in order to record the early history of a word that may later become naturalized. Some words may remain "denizens" for centuries, Murray pointed out, such as "phenomenon" treated as Greek, "genus" as Latin, and "aide-de-camp" as French. When a word is borrowed, its etymology may be traced through its descent in its original language.

Some early philosophies have assumed that there is a mystic relation between the present use of a word and its origin and that etymology is a search for the "true meaning." The recognition of continuous linguistic change establishes, however, that etymology is no more than early history, sometimes as reconstructed on the basis of relationships and known sound changes. Ingenuity in etymologizing is dangerous, and even plausibility can be misleading, but ascertained fact has overriding importance. It is curious that recent slang is often more uncertain in its origin than words of long history.

GRAMMATICAL INFORMATION

Dictionaries are obliged to contain the two basic kinds of words of a language—the "function words" (those that perform the grammatical functions in a language, such as the articles, pronouns, prepositions, and conjunctions) and the "referential words" (those that symbolize entities outside the language system). Each kind must be treated in a suitable way. Dictionaries have been much criticized for not including a sufficiency of grammatical information. It is usual to mark the part of speech, but not the categories of mass noun and count noun. (A mass noun, such as "milk" or "oxygen," cannot ordinarily be used in the plural, while a count noun is any noun that can be pluralized.) Such information is given in some dictionaries designed for teaching, and the technique could well be adopted more generally. The irregular inflections must be given, showing that one says "goose," "geese," but not "moose," "meese." Or in the verbs one says "walk," "walked," but "ride," "rode." It is usual to treat the different parts of speech as separate lexical entries, as in "to walk" and "to take a walk," requiring a parallel list of senses, but Edward Lee Thorndike, in his school dictionaries, experimented with grouping the parts of speech together when they had a similar sense.

Grammar and vocabulary

The relation of grammar to the vocabulary is the subject of considerable controversy among linguists. If one considers the analysis of language as one unified enterprise, then the grammar is central and the lexical units are inserted at some point in the analysis. Another view is that the division is into coordinate branches, such as phonology, syntax, and lexicon. Certainly lexicographers try to take advantage of all findings made by grammarians.

SENSE DIVISION AND DEFINITION

A language like English has so many complex developments in the senses—*i.e.*, the particular meanings—of its words that the task of the lexicographer is difficult. It is generally accepted that "meaning" is a suffusing characteristic of all language by definition, and the attempt to slice meaning into "senses" must be done arbitrarily by the person analyzing the language. This is where collected contexts form the basis of the lexicographer's judgment. He sorts the quotations into piles on the basis of similarities and differences and he may have to discard "transitional" examples. Figurative developments, such as the "mouth" of a river or the "foot" of a hill, make complications in the relationships.

For the order in which the senses of words are given, the order of historical development has been chiefly used. For an old word like "earth," the information may be insufficient. The editors of the *OED* had to give up, because, they said, "Men's notions of the shape and position of the earth have so greatly changed since Old Teutonic times"; they were obliged to compromise with a logical order. Sometimes, but not always, a word seems to have a "core," or central, meaning from which other meanings develop. If the historical order is followed, the obsolete and archaic meanings may have to appear first; and, therefore, some popular dictionaries give the most important meaning first and work down to the rare and occasional meanings at the end. The so-called "semantic count," giving senses in order of frequency, has also been used.

There seems to be no one method that is best for defining all words. The lexicographer must use artistry in selecting the ways that will convey a sense accurately and succinctly. He attempts to find what is "criterial" in a particular meaning, but he can also give further detail until he runs into the area of the encyclopaedic.

In logical theory it would be ideal to have a "metalanguage" in which definitions could be stated, but nothing of the sort is available for popular use. A "defining vocabulary" can be established, and in school dictionaries the definitions use simple words. In the last analysis all definitions have to fall back on undefined terms (to be accepted like axioms) that symbolize first-order experience of life. In this connection the logician Willard Quine has argued that lexicography is basically concerned with synonymy.

USAGE LABELS

Variations in language use

Part of the information that a dictionary should give concerns the restrictions and constraints on the use of words, commonly called usage labelling. There is great variation in language use in many dimensions—temporal, geographical, and cultural. The people who make a two-part division into "correct" and "incorrect" show that they do not understand how language works. The valuation does not lie in the word itself but in the appropriateness of the context. Therefore, it is preferable to be sparing in the use of labels and to allow the tone to become apparent from the illustrative examples. An important distinction was put forward in 1948 by an American philologist, John S. Kenyon, when he discriminated between "cultural levels," which refer to the degree of education and cultivation of a person, and "functional varieties," which refer to the styles of speech suitable to particular situations. Thus a cultivated person rightly uses informal or colloquial language when at ease with friends.

A lexicographer is faced with the difficult task of selecting a suitable set of labels. In the temporal categories, labels such as obsolete, obsolescent, archaic, and old-fashioned are dangerous, because some speakers have long memories and might use old words very naturally. The national labels are problematical, because words move easily from one branch of the language to another. The word "blizzard," for instance, is no doubt an Americanism in origin, but, since the 1880s, it has been so well known over the English-speaking world that a national label would be misleading. The label "dialect" or "regional," either for England or America, offers many problems, for alleged "boundaries" are permeable. The label "colloquial" was much misunderstood, and now "informal" is often used in its place. There may be a "poetic vocabulary" that needs labelling, and few people will agree on any definition of "slang."

It is revealing that in early printings of the Merriam-Webster *Third New International* under the word "cock-eyed," marked "slang," one of the quotations is by a careful stylist named Jacques Barzun; in order to use effective English, as he does, this cultivated writer is willing to draw upon slang. Some would argue that in marking the use as "slang," the Merriam-Webster staff was not sufficiently "permissive."

Some dictionaries wisely include special paragraphs on the constraints of usage, sometimes as a "synonymy" and sometimes as a "usage note."

ILLUSTRATIVE QUOTATIONS

Citation of sources

Dictionaries of the past have copied shamelessly from one to another, but the collecting of a file of illustrative quotations makes possible a fresh, original treatment. Scholarly works like the *OED* and its supplementations follow the canon of always using the earliest quotation and the latest for an obsolete word; in between, the quotations are selected for revealing facets of usage or for "forcing" a meaning. The criterion of use by only the best writers does not hold for a truly historical dictionary, because a "low" source may be especially revealing. The giving of exact source citations is not a matter of pedantry but es-

tablishes the scientific basis by which others can check the evidence. A different set of quotations, accurately attested, might have led to a different treatment. Thus the phrase "illustrative quotation" is something of a misnomer, for the quotations are more than "illustrative"; they form the basic evidence from which conclusions are drawn. It is the work of the editor to decide when the collections are sufficient—"ripe," as it were—to move from the collecting stage to the editing stage.

A small-sized dictionary may advantageously use made-up sentences, because an aptly framed "forcing" context can tell more than a definition. In fact, the habitual collocations of a word (the surrounding words with which it usually appears) may be revealing of the nature of a word. "Dictionaries of collocations" may be a step forward in future lexicography.

TECHNOLOGICAL AIDS

The development of machine aids, such as the computer, has been heralded by some as ushering in a new era in lexicography. Although the computer can do well in many tasks of great drudgery—mechanical excerpting of texts, alphabetizing, and classifying by designated descriptors—it is limited to what a human being tells it to do. It is difficult for a computer to sort out homographs—separate words that are spelled alike; and, at the editing stage, the delicate decisions must be humanly made.

Uses for computers

The computer can be used to good advantage in the compilation of concordances of individual authors or of limited texts, and then one type of dictionary could be made by a summation of concordances. Such a procedure, with a large body of literature like that of the Renaissance, would overwhelm an editor. More feasible, perhaps, is the establishment of a computerized archive that would never be published but would serve as a storehouse from which, by advanced retrieval methods, the desired information could be called forth at will. The *Trésor de la langue française* of Nancy, already mentioned, is a step in this direction.

ATTITUDES OF SOCIETY

Without a doubt, dictionaries have been a conservative force for many hundreds of years, not only in countries that have had an official academy that has the national language as part of its province but also in the English-speaking countries, in which academies have been spurned. Well-entrenched popular attitudes account for this. A Neoplatonic outlook assumes that there exists an ideal form of language from which faltering human beings have departed and that dictionaries might bring people closer to the perfect language. Also, there is a widespread "yearning for certainty," a seeking for guidance amid the wilderness of possible forms. Thus, people welcome self-proclaimed "supreme authorities."

Americans have had additional reasons for their homage to the dictionary. In colonial times Americans felt themselves to be far from the centre of civilization and were willing to accept a book standard in order to learn what they thought prevailed in England. This linguistic colonialism lasted a long time and set the pattern of accepting the dictionary as a "lawgiver." In 1869, a cultural leader declared: "Upon the proper spelling, pronunciation, etymology, and definition of words, a dictionary might be made to which high and almost absolute authority might justly be awarded." In this vein teachers have taken pains to inculcate "the dictionary habit" in their pupils. Rather than observe the language around them, as Englishmen commonly do, Americans give up their autonomy and fly to a dictionary to settle questions on language. This call for dogmatic prescription has been a source of uneasiness to lexicographers, most of whom now argue that all they can do legitimately is to describe how the language has been used.

Observance of taboos

Social attitudes have affected the dictionaries also in the enforcement of certain taboos. Certain words commonly called obscene have been omitted, and, thus, irrational taboos have been strengthened. If the sex words were given in their alphabetical place, with suitable labels, the false attitudes in society would more readily be cleansed. A perennial problem in lexicography is the treatment of the terms of ethnic insult. There is constant social pressure for leaving them out, and some dictionaries have succumbed to it, but it may be that an enlightened attitude shows that the open discussion of prejudices is the best way of getting rid of them.

The greatest value of a dictionary is in giving access to the full resources of a language and as a source of information that will enhance free enjoyment of the mother tongue.

Major dictionaries

For the English language the important dictionaries have already been cited in the appropriate sections; but the supreme achievement represented by the *OED* should be emphasized again. Major dictionaries in some other languages are discussed below.

Dictionaries of the Romance languages

For the French language, the Académie's dictionary was released in several editions and manifested conservative views about the vocabulary, but three other works were actually more serviceable—the *Petit Larousse: dictionnaire encyclopédique pour tous* (1959); a new edition of the famous Littré, *Dictionnaire de la langue française* (1974); and Paul Robert's *Dictionnaire alphabétique et analogique de la langue française* (1960–64). For French etymology alone, the standard work was Walther von Wartburg's *Französisches etymologisches Wörterbuch.*

Among other Romance tongues, Italian has had many dictionaries. The Accademia della Crusca of Florence furnished its *Vocabolario* in a first edition in 1612, but the edition begun in 1863 bogged down at the letter *O* in 1923. There was also the dictionary by G. Devoto and G.C. Oli, *Dizionario della lingua italiana* (1971). Following the model of the *OED* was the still uncompleted *Grande dizionario della lingua italiana* (1961), edited by Salvatore Battaglia. Very serviceable to English speakers is the *Italian Dictionary* of Alfred Hoare (1915) and that of Barbara Reynolds, begun in 1962. For Spanish, the Real Academia Española in Madrid did well since its first edition in 1726–39.

For the German language, a great dictionary begun by the brothers Grimm, completed in 1960, was re-edited in a project that took many years, and it appeared online in 2003. A standard work was Hermann Paul's *Deutsches Wörterbuch*, which first appeared in 1897 but was later reissued in several editions. The national dictionaries in the Scandinavian countries were mentioned above, but another work done with special scholarly skill was also noteworthy: Einar Haugen, editor in chief, *Norwegian English Dictionary* (Madison, Wisconsin [Oslo printed], 1965), dealing with the two official languages of Norway, Bokmål and Nynorsk. The Afrikaans language was the subject of several dictionaries. Publication of *Woordeboek van die Afrikaanse taal* began at Pretoria in 1950 as a collaboration of the best scholars in South Africa. A full dictionary of Yiddish has yet to be written but one scholarly source was Uriel Weinreich's *Modern English-Yiddish, Yiddish-English Dictionary* (1968).

Greek lexicography offers special difficulties because of the long range of illustrious literature that must be covered and the split in recent centuries between Katharevusa, the literary language, and Demotic, the language of everyday life. For the English-speaking world, the standard work for Ancient Greek was long the work by Henry George Liddell and Robert Scott, *A Greek-English Lexicon*, published in a first edition in 1843. For Russian the Soviet Academy of Arts has produced a useful work in four volumes (1957–61). Many linguists have attempted to cover Arabic; for long the most useful work was that of Hans Wehr, as translated and edited by J. Milton Cowan, *A Dictionary of Modern Written Arabic* (1961). For Japanese a standard source is the *Dai-jiten* ("Great Dictionary"), issued at Tokyo (1934–36). One of the best-known Chinese dictionaries, *Tz'u hai*, was revised in 1969 and published in Taipei, Taiwan. (A.W.Re./Ed.)

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Endocrine Systems

Endocrinology deals with the structure and function of glands that secrete materials internally. It is important to distinguish between an endocrine gland, which discharges substances called hormones directly into the bloodstream or lymph system, and an exocrine gland, which secretes substances through a duct opening in the gland onto an external or internal body surface. Salivary and sweat glands, examples of exocrine glands, secrete saliva and sweat, respectively, which act locally at the site of duct openings. In contrast, hormones that are secreted in minuscule quantities by endocrine glands, are transported by the circulation to exert powerful effects on tissues remote from the site of secretion.

As far back as 3000 BC, the ancient Chinese diagnosed some endocrinologic disorders and were able to provide effective treatments. For example, seaweed, which is rich in iodine, was prescribed for the treatment of goitre (enlargement of the thyroid gland). Perhaps the earliest demonstration in humans of direct endocrinologic intervention was the castration of men who could then be relied upon, more or less, to safeguard the chastity of women living in harems. During the Middle Ages and persisting well into the 19th century, it was a popular practice to castrate pubertal boys to preserve the purity of their treble voices. Castration established the testicle as the source of substances responsible for the development and maintenance of "maleness."

This knowledge led to an abiding interest in restoring or enhancing male sexual powers. John Hunter, an 18th-century Scottish surgeon, anatomist, and physiologist who practiced in London, transplanted successfully the testis (testicle) of a rooster into the abdomen of a hen. Charles-Édouard Brown-Séquard, a 19th-century French neurologist and physiologist, asserted that testes contained an invigorating, rejuvenating substance. His conclusions were based, in part, on observations obtained after he had injected himself with an extract of the testicle of a dog or of a guinea pig to which water had been added. These experiments were advances in that they resulted in the widespread use of organ extracts (organotherapy).

Modern endocrinology, however, is largely a creation of the 20th century. Its scientific origin is firmly rooted in the studies of Claude Bernard (1813–78), a brilliant French physiologist who made the key observation that complex organisms, such as humans, go to great lengths to preserve the constancy of what he called the "milieu intérieur" (internal environment). Later, an American physiologist, Walter Bradford Cannon (1871–1945), used the term homeostasis to describe this inner constancy.

The endocrine system, in association with the nervous system and the immune system, regulates the body's internal activities and external interactions to preserve the static internal environment. This control system permits the prime functions of living organisms—growth, development, and reproduction—to proceed in an orderly, stable fashion; it is exquisitely self-regulating so that any disruption of the normal internal environment by internal or external events is resisted by powerful countermeasures. When this resistance is overcome, sickness ensues.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 421 and 423.

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Traditional endocrinology

Because endocrinology involves an actively expanding body of knowledge, its borders remain difficult to define. The traditional core of an endocrine system, however, consists of (1) an endocrine gland, (2) its hormonal secretion, (3) a responding tissue containing a specific receptor to which the hormone will become bound, and (4) the action that results after the hormone becomes bound, termed the postreceptor response.

Embryonic origin of endocrine glands

Each endocrine gland consists of a group of specialized cells that have a common origin in the developing embryo. Many endocrine glands are derived from cells that arise in the embryonic digestive system (*e.g.*, the thyroid and pancreas) or from cells that migrate from the embryonic nervous system (*e.g.*, the parathyroid and adrenal medulla). Still others arise from a region of the embryo known as the urogenital ridge (ovary, testis, and adrenal cortex). The pituitary gland is derived from cells that originate in both the nervous system and the digestive tract. Each endocrine gland has a rich supply of blood, which is directly related to its role in synthesizing and secreting hormones. Many endocrine glands secrete more than one hormone. Some organs function both as exocrine glands and as endocrine glands. The pancreas is the best-known example.

In addition to the more traditional endocrine cells described above, specially modified nerve cells within the nervous system secrete important hormones into the blood. These special nerve cells are called neurosecretory cells, and their secretions are termed neurohormones to distinguish them from the hormones produced by traditional endocrine cells. The areas of the nervous system that produce neurohormones also have a rich vascular supply, and the neurohormones are either released into the blood or stored in adjacent blood-rich areas (called neurohemal organs) until needed.

Most hormones are one of two types: proteins (including peptides and modified amino acids) or steroids. The majority of hormones are the protein type. They are highly soluble in water and can be transported readily through the blood. The protein hormones, when initially synthesized within the cell, are contained within larger, biologically inert molecules called prohormones. The inactive portion of the prohormone is split away so that one or more active fragments that are released from the cell circulate through the blood. A smaller number of hormones are the water-soluble, fatty acid steroid hormones, all of which are synthesized from the precursor molecule cholesterol. These lipid hormones are transported through the blood by first being bound to proteins in the blood.

All body tissues that respond to a specific hormone contain specially shaped molecular configurations called receptors. These receptors are found on the surface of target cells, in the case of protein and peptide hormones, or within the cytoplasm, in the case of steroids and modified amino acid hormones. Each receptor has a strong, highly specific affinity (attraction) for a particular hormone.

This arrangement permits a specific hormone to have an effect only on those tissues for which it is "targeted," namely, those that are equipped with specific binding receptors. Usually, one segment of the hormone molecule exhibits a strong chemical affinity for the receptor while another area is responsible for initiating its specific action. Thus, hormonal actions are not general throughout the body but rather are aimed at specific target tissues.

The hormone-receptor complex

The hormone-receptor complex that is formed then activates a chain of specific chemical responses within the cells of the target tissue to complete the hormonal action. This action may be the result of the activation of enzymes within the target cell, of the interactions of the hormone-receptor complex with the nucleus of the cell, and consequent stimulation of new protein synthesis, or of a combination of both. It may even result in secretion of another hormone.

General features

THE NATURE OF ENDOCRINE REGULATION

Endocrine gland secretion is not a haphazard process; it is subject to precise, intricate control at several levels so that its effect may be integrated with those of the nervous system and the immune system. The simplest level of control resides at the endocrine gland itself. Characteristically, the signal for an endocrine gland to release more or

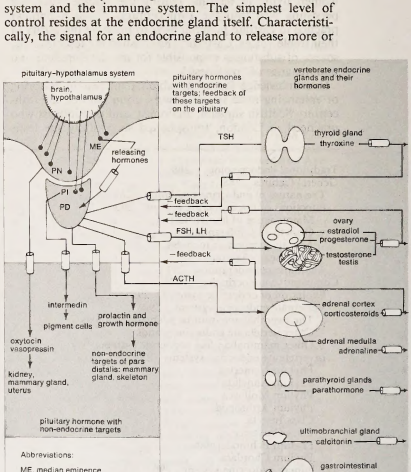


Figure 1: *Relationships of endocrine glands.* At the upper left is the pituitary-hypothalamus axis, and on the upper right are the endocrine target glands controlled through negative feedback by this axis. At the lower left are nonendocrine target organs of this axis. At the lower right are some endocrine glands that are not directly affected by the feedback mechanisms that regulate the endocrine and nonendocrine target organs.

less of its hormone is the level of some substance, either a hormone that influences the action of a gland (called a tropic hormone), a biochemical product such as glucose, or a biologically important element such as potassium or calcium. Because the endocrine gland has a rich supply of blood, it is able to detect changes in the level of this regulating substance.

Simple negative feedback

Some endocrine glands, for example the parathyroid glands located in the neck, are controlled largely by a simple negative feedback mechanism as demonstrated in Figure 2. Parathyroid hormone, known as parathormone (A), acts on its major target organ, bone (B), and other tissues to transport calcium into the blood, raising the serum calcium level (C). Elevated serum calcium levels inhibit the secretion of parathormone by the parathyroid glands (D). Thus, if for any reason serum calcium levels become elevated, parathormone secretion is blocked and calcium is not secreted into the serum from bone; the serum calcium level then falls back into the normal range. If, on the other hand, the serum calcium level should fall (E), the parathyroids are no longer inhibited from releasing parathormone and parathyroid gland activity is stimulated. (F) The increased circulating levels of parathormone stimulate increased dissolution of bone, releasing calcium. Thus, calcium enters into the serum from bone, and the serum calcium concentration rises until it reaches a normal level. In this fashion, in individuals with normal parathyroid glands, serum calcium levels are maintained within a narrow range even in the face of large changes in calcium intake or excessive losses of calcium from the body.

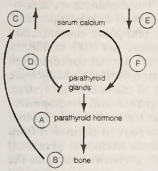


Figure 2: Control of parathyroid hormone secretion (see text).

Control of the hormonal secretions of a number of other endocrine glands is more complex because the glands are, themselves, target organs of a regulatory system called the hypothalamic-pituitary-target organ axis. Glands of this type include the thyroid, the adrenal cortex, and the gonads (testes and ovaries). The major mechanism involves interconnecting negative feedback loops, each similar to that described above, which involve the hypothalamus (a structure located at the base of the brain and above the pituitary), the anterior pituitary, and the target organ. The hypothalamus stimulates the pituitary, through neurohormones, to secrete pituitary hormones, which affect any of a number of target organs. The hypothalamic-pituitary-target organ axis is one of the more elegant devices to be found in nature. A generalized representation is illustrated in Figure 3 and discussed below.

The target gland secretes its hormone (target gland hormone), which (A) combines with the receptors of a secondary target tissue and is then inactivated. This continues until the concentration of target gland hormone in the blood exceeds the amount necessary to bind all of the tissue receptors. The effect of the target gland hormone on the secondary target tissue is quantitative; that is, within limits, the greater the amount of target gland hormone bound to receptors in the secondary target tissue, the greater the secondary target tissue cell response. The target gland hormone also binds to specific receptors in the anterior pituitary (B) to inhibit the secretion of pituitary-stimulating hormone (the hormone that stimulates the target gland to secrete more target gland hormone). As the concentration of the target gland hormone in the blood rises, there is an appropriate decrease in the production of pituitary-stimulating hormone. Thus, there will be less activation (C) of the target gland to produce its hormone. The end result of this feedback mechanism is that the high level of target hormone circulating in the bloodstream falls back to normal.

Conversely, as more target gland hormone is bound (A) to receptors in the secondary target tissue, the levels of target gland hormone circulating in the bloodstream falls. The overall inhibitory effects of target gland hormone on the pituitary gland then is reduced. Low levels of target gland hormone thus stimulate production of more pituitary-stimulating hormone (C), which in turn stimulates the secretion of target gland hormone by the target gland, until (B) the concentration of target gland hormone in the blood increases to a normal level.

A second, similar negative feedback loop is superimposed on the first. The target gland hormone binds to nerve cells in the hypothalamus (D), which inhibit the secretion of specific hypothalamic-releasing hormones (neurohormones) that stimulate the secretion of pituitary hormone (an important element in the previous negative feedback loop). The concentrations of hypothalamic-releasing hormones (E) within a set of veins that connects the hypothalamus and the pituitary gland (the hypophyseal-portal circulation) is reduced.

Nervous influences

The importance of this second loop (D and E) lies in the fact that the nerve cells of the hypothalamus communicate with nervous influences that extend down from the brain (G), including the cerebral cortex (the centre for higher mental functions, movement, perceptions, etc.), thus permitting the endocrine system to respond to physical and emotional stresses. The mechanism involves the interruption of the primary feedback loop (B and C) so that the concentrations of hormones in the blood can be increased or decreased appropriately in response to environmental stresses perceived by the nervous system (see below *The human endocrine system: The hypothalamus*). If this were not available, all blood hormones would be locked in at normal concentrations, even at times when it would be important to the body for these hormones to diverge from normal levels. Similarly, appropriate endocrinologic responses can be achieved from stimuli resulting from signals generated through the immune system to threats (such as bacterial invasion) from within the organism.

Finally, a third short loop (E and F) directly inhibits the release of a specific hypothalamic-releasing hormone by a pituitary hormone. In this fashion, concentrations of pituitary, thyroid, adrenal cortex, and gonadal hormones in the blood are maintained at normal, homeostatic levels, but, when necessary, the hormonal levels may be altered dramatically to meet changing circumstances of the internal or external environment.

This traditional view of the mechanisms that control endocrine secretion has been modified by evidence pointing to important supplemental control mechanisms. When, as is usually the case, more than one cell type is found within a single endocrine gland, the hormones secreted by one cell may exert a direct modulating effect upon the secretions of its immediate neighbour of a different cell type. This form of control is known as paracrine function. Similarly, the secretions of one endocrine cell may affect the activity of a neighbour cell of identical type, an activity known as autocrine function. Thus, endocrine cell activity may be modulated directly from within the endocrine gland itself without the need for hormones to enter the general circulation.

Paracrine and autocrine functions

Excluding from the definition of a hormone the requirement that it act at a site remote from the secreting endocrine cell allows additional classes of bioactive materials to be considered as hormones. Neurotransmitters, a group of chemical compounds of variable composition, are secreted at all synapses (junctions between nerve cells over which nervous impulses must pass). They facilitate or inhibit the transmission of neural impulses and have given rise to the hybrid science of neuroendocrinology (the branch of medicine that studies the interaction of the nervous system and the endocrine system). A second group of novel bioactive substances are called the prostaglandins, a complex group of fatty acids that are formed and secreted

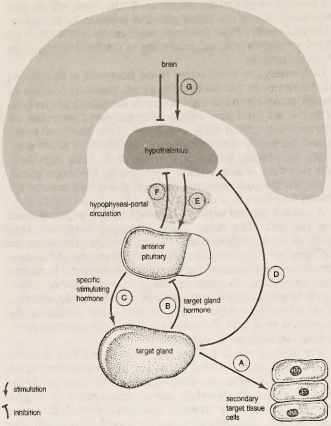


Figure 3: Hypothalamic-pituitary-target organ axis (see text).

by many tissues. They mediate important biological effects in almost every organ system of the body.

Growth factors

Another group of substances with hormonelike actions is called growth factors. These are substances that stimulate the growth of specific target tissue cells. They are distinct from the usual members of the endocrine family of growth hormones in that they were identified only after it was noted that target cells grown outside the organism in tissue culture could be stimulated to grow and reproduce by gland or tissue extracts chemically distinct from any known growth hormone.

Still another area of hormonal classification that has come under intensive investigation is the effect of endocrines on animal behaviour. While simple, direct hormonal effects on human behaviour are difficult to document because of the complexities of human motivation, there are many convincing demonstrations of hormone-mediated behaviour in other life forms. A special case is that of the pheromone, a substance generated by an organism that influences, by its odour, the behaviour of another organism of the same species. An often-quoted example is the musky scent of the females of many species, which provokes sexual excitation in the male. Such devices have obvious adaptive value for species survival.

FUNCTIONS OF THE ENDOCRINE SYSTEM

Maintenance of homeostasis. For an organism to function normally and effectively, it is necessary that the processes of its tissues operate smoothly and conjointly in a stable setting. The endocrine system provides an essential mechanism, called homeostasis, that integrates body activities and at the same time ensures that the composition of the body fluids bathing all of the constituent cells remains constant.

Scientists have postulated that the concentrations of the various salts present in the fluids of the body closely resemble the concentrations of salts in the primordial seas, which nourished the simple organisms from which increasingly complex species have evolved. Since any change in the salt composition in fluids that surround the cells (extracellular fluid), such as the fluid portion of the circulating blood (the intravascular plasma or serum), would necessitate large compensating changes in the salt concentrations within cells, the constancy of these salts (called electrolytes) is closely guarded. Even small changes in the circulating levels of these electrolytes (which include sodium, potassium, chloride, calcium, magnesium, and phosphate) elicit prompt, appropriate responses from the endocrine system, by employing negative feedback regulatory mechanisms similar to those described above, in order to restore normal concentrations.

Homeostasis

Not only is the level of each individual electrolyte maintained through homeostasis, but the total concentration of all of the electrolytes per unit of fluid (called the osmolality) is kept constant as well. If this were not the case, an increase in extracellular osmolality (or an increase in the concentration of electrolytes per unit of fluid) would result in the movement of intracellular fluid out of the cells, across the cell membrane, and into the extracellular compartment. Because the kidneys would excrete much of the fluid from the expanded extracellular volume, dehydration would be the result. Conversely, decreased plasma osmolality (or a decrease in the concentration of electrolytes per unit of fluid) would lead to a buildup of fluid within the cell.

Another homeostatic mechanism involves not an adjustment of the concentration of electrolytes in plasma but, rather, the maintenance of a normal total plasma volume. If the total volume of fluid within the circulation increases (a condition known as overhydration), the pressure against the walls of the blood vessels and the heart increase as well, stimulating sensitive areas in heart and vessel walls to release hormones that modulate the excretion of water and electrolytes by the kidney, thus reducing the total plasma volume to normal.

Growth and differentiation. Despite the many mechanisms designed to maintain a constant internal environment, the organism itself is subject to change; it is born (or hatches), it matures, and it ages. These changes are accompanied by supportive variations in body fluid composition. For example, the normal serum phosphate concentration in a child is about six milligrams per 100 millilitres, whereas about half that value is the normal concentration in an adult. These and other more striking changes are part of a second major function of the endocrine system, namely, the control of normal growth and development. The mammalian fetus develops in the uterus of the mother under the powerful influence not only of hormones from its own endocrine glands but from hormones generated in the mother's placenta as well, a system known as the

Control of growth

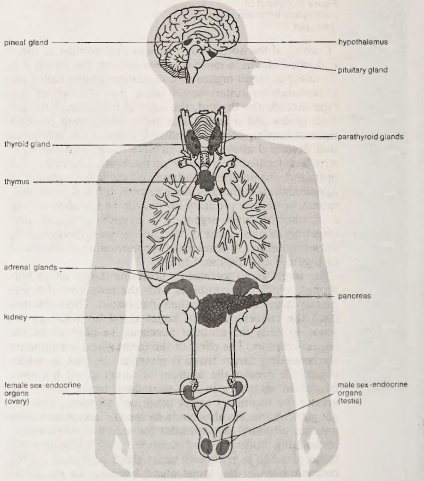


Figure 4: The human endocrine glands.

fetoplacental unit. Maternal endocrine glands assure that a proper mixture of nutrients is transmitted by way of the placenta to the growing fetus. Hormones also are present in the mother's milk and are transferred to the suckling young. There is evidence for the transmission of hormones into the eggs of nonmammals, which may influence the development of the embryo.

Sexual differentiation of the fetus into a male or a female is also controlled by delicately timed hormonal changes. After birth and a period of steady growth in infancy and childhood, the changes associated with puberty and adolescence take place. This dramatic transformation of an adolescent into a physically mature adult is also initiated and controlled by the endocrine system. Finally, as the endocrinology of aging has come under intensive investigation, changes associated with the process of normal aging and senescence have been discovered.

Adaptive responses to stress. Throughout the life of the organism endocrine influences are at play to enhance the ability of the body to respond to internal and external stressful stimuli. These changes allow not only the individual organism but also the species to survive. Early studies by Cannon led him to the thesis that acutely threatened animals respond with multiple physical changes, including endocrine changes, that prepare them to react or retreat, a process known as "the fight or flight reaction."

Adaptive responses for more prolonged stresses also occur. For example, in states of malnutrition typical of the self-induced semistarvation condition called anorexia nervosa, there is reduced secretion of thyroid hormones (hormones that generally stimulate metabolic processes of the body), leading to a lower metabolic rate. This change reduces the rate of the consumption of the body's fuel, and thus reduces the rate of consumption of the remaining energy stores. This change has obvious survival value; death from starvation is deferred.

Parenting behaviour. The endocrine system, particularly the hypothalamus, the anterior pituitary, and the gonads, is intimately involved in reproductive behaviour by providing physical, visual, and olfactory (pheromonal) signals that arouse the sexual interest of the male and the receptivity of the female. Furthermore, there are powerful endocrine influences on parental behaviour in all species, probably including humans.

Pheromones

ANATOMIC CONSIDERATIONS

Figure 4 illustrates those secretory organs that have traditionally made up the human endocrine system. While these obviously glandular structures synthesize and secrete specific hormones (Table 1), studies have revealed that most body tissues may also function as endocrine organs. The growing list includes the lungs, the heart, the skeletal muscles, the uterus, the kidneys, the salivary glands, and the lining of the gastrointestinal tract. Finally, as mentioned above, bundles of nerve cells, called nuclei, have evolved into classical endocrine organs; they secrete neurohormones into the bloodstream. (T.B.S.)

Comparative endocrinology

Usefulness of comparative studies

Comparative endocrinologists investigate the evolution of endocrine systems and the role of these systems in animals' adaptation to their environments and their production of offspring. Studies of nonmammalian animals have provided information that has furthered research in mammalian endocrinology, including that of humans. For example, the actions of a pituitary hormone, prolactin, on the control of body water and salt content were first discovered in fishes and later led to the demonstration of similar mechanisms in mammals. The mediating role of local ovarian secretions (paracrine function) in the maturation of oocytes (eggs) was discovered in starfishes and only later extended to vertebrates. The important role of thyroid hormones during embryonic development was first studied thoroughly in tadpoles during the early 1900s. In addition, the isolation and purification of many mammalian hormones was made possible in large part by using other vertebrates as bioassay systems; that is, primitive animals have served as relatively simple, sensitive indicators of the amount of hormone activity in extracts prepared from mammalian endocrine glands. Finally, some vertebrate and invertebrate animals have provided "model systems" for research that have yielded valuable information on the nature of hormone receptors and the mechanisms of hormone action. For example, one of the most intensively studied systems for understanding hormone actions on target tissues has been the receptors for progesterone and estrogens (hormones secreted by the gonads) from the oviducts of chickens.

Table 1: The Human Endocrine System

gland or tissue	hormone	chemical nature
Testis	testosterone	steroid
Ovary	estrogens (estradiol, estrone, estriol)	steroids
	inhibin (folliculostin)	polypeptide?
	progesterone	steroid
	relaxin	polypeptide
Thyroid gland	thyroxine (T_4)	amino acid
	triiodothyronine (T_3)	amino acid
Adrenal gland		
Medulla	epinephrine	amine
	norepinephrine	amine
	dopamine	steroid
Cortex	cortisol	steroid
	corticosterone	steroid
	aldosterone	steroid
	androgens	steroid
	estrogens	steroid
Pituitary gland		
Anterior lobe	corticotropin (adrenocorticotropin, ACTH)	polypeptide
	growth hormone (GH or somatotropin)	protein
	thyrotropin (thyroid-stimulating hormone, TSH)	glycoprotein
	follicle-stimulating hormone (FSH)	glycoprotein
	luteinizing hormone (LH, interstitial cell stimulating hormone, ICSH)	glycoprotein
	prolactin (PRL, luteotropic hormone, LTH, lactogenic hormone, mammotropin)	protein
Posterior lobe	oxytocin	polypeptide
	vasopressin (antidiuretic hormone, ADH)	polypeptide
Intermediate lobe tissue	α-melanocyte-stimulating* hormone (α-MSH)	polypeptide
	β-melanocyte-stimulating* hormone (β-MSH)	polypeptide
Hypothalamus	corticotropin-releasing hormone (CRH)	polypeptide?
	growth hormone-releasing hormone (GHRH)	polypeptide?
	thyrotropin-releasing hormone (TRH)	polypeptide
	follicle-stimulating hormone (FSH)	polypeptide?
	gonadotropin-releasing hormone (GnRH)	polypeptide
	prolactin-inhibiting factor (PIF)	polypeptide?
	somatostatin	polypeptide
	gastrointestinal neuropeptide	polypeptide
Pancreatic islets	glucagon	polypeptide
	insulin	polypeptide
	somatostatin	polypeptide
	pancreatic polypeptide	polypeptide
Parathyroid gland	parathyroid hormone (parathormone)	polypeptide
	calcitonin	polypeptide
Skin, liver, kidney	calciferols	steroids
Gastrointestinal mucosa		
Stomach	gastrin	polypeptide
Duodenum	cholecystokinin (CCK)	polypeptide
	secretin	polypeptide
	gastric-inhibitory polypeptide (GIP)	polypeptide
	vasoactive intestinal peptide (VIP)	polypeptide
	villikinin	—
	enterocrinin	—
Thymus	thymosin	polypeptide
Pineal	melatonin	amine (not secreted?)
Kidneys	renin	protein
	erythropoietin	protein?
Placenta	human chorionic gonadotropin (HCG)	glycoprotein
	human chorionic somatomammotropin (HCS)	protein
	renin	protein
	estrogens	steroids
	androgens	steroids
	progesterone	steroid
Multiple tissues	somatomedins (insulin-like growth factors)	polypeptides
	prostaglandins	steroids

*Intermediate lobe hormones referred to collectively as melanotropin or intermedin.

An understanding of how the endocrine system is regulated in nonmammals also provides essential information for regulating natural populations or captive animals. Artificial control of salmon reproduction has had important implications for the salmon industry as a whole. Some successful attempts at reducing pest insect species have been based on the knowledge of pheromones. Understanding the endocrinology of a rare species may permit it to be bred successfully in captivity and thus prevent it from becoming extinct. Future research may even lead to the reintroduction of some endangered species into natural habitats.

EVOLUTION OF ENDOCRINE SYSTEMS

Primitive endocrine glands

The most primitive endocrine systems seem to be those of the neurosecretory type, in which the nervous system either secretes neurohormones (hormones that act on, or are secreted by, nervous tissue) directly into the circulation or stores them in neurohemal organs (neurons whose endings directly contact blood vessels, allowing neurohormones to be secreted into the circulation), from which they are released in large amounts as needed. True endocrine glands probably evolved later in the evolutionary history of the animal kingdom as separate, hormone-secreting structures. Some of the cells of these endocrine glands are derived from nerve cells that migrated during the process of evolution from the nervous system to various locations in the body. These independent endocrine glands have been described only in arthropods (where neurohormones are still the dominant type of endocrine messenger) and in vertebrates (where they are best developed).

It has become obvious that many of the hormones previously ascribed only to vertebrates are secreted by invertebrates as well (for example, the pancreatic hormone insulin). Likewise, many invertebrate hormones have been discovered in the tissues of vertebrates, including those of humans. Some of these molecules are even synthesized and employed as chemical regulators, similar to hormones in higher animals, by unicellular animals and plants. Thus, the history of endocrinologic regulators has ancient beginnings, and the major changes that took place during evolution would seem to centre around the uses to which these molecules were put.

VERTEBRATE ENDOCRINE SYSTEMS

Evolutionary relationships

Vertebrates (phylum Vertebrata) are separable into at least seven discrete classes that represent evolutionary groupings of related animals with common features. The class Agnatha, or the jawless fishes, is the most primitive group. Class Chondrichthyes and class Osteichthyes are jawed fishes that had their origins, millions of years ago, with the Agnatha. The Chondrichthyes are the cartilaginous fishes, such as sharks and rays, while the Osteichthyes are the bony fishes. Familiar bony fishes such as goldfish, trout, and bass are members of the most advanced subgroup of bony fishes, the teleosts, which developed lungs and first invaded land. From the teleosts evolved the class Amphibia, which includes frogs and toads. The amphibians gave rise to the class Reptilia, which became more adapted to land and diverged along several evolutionary lines. Among the groups descending from the primitive reptiles were turtles, dinosaurs, crocodilians (alligators, crocodiles), snakes, and lizards. Birds (class Aves) and mammals (class Mammalia) later evolved from separate groups of reptiles. Amphibians, reptiles, birds, and mammals, collectively, are referred to as the tetrapod (four-footed) vertebrates.

The human endocrine system is the product of millions of years of evolution, and it should not be surprising that the endocrine glands and associated hormones of the human endocrine system have their counterparts in the endocrine systems of more primitive vertebrates. By examining these animals it is possible to document the emergence of the hypothalamic-pituitary-target organ axis, as well as many other endocrine glands, during the evolution of fishes that preceded the origin of terrestrial vertebrates.

The hypothalamic-pituitary-target organ axis. The hypothalamic-pituitary-target organ axes of all vertebrates are similar. The hypothalamic neurosecretory system is poorly developed in the most primitive of the living Agnatha vertebrates, the hagfishes, but all of the basic rudiments are present in the closely related lampreys. In most of the more advanced jawed fishes there are several well-developed neurosecretory centres (nuclei) in the hypothalamus that produce neurohormones. These centres become more clearly defined and increase in the number of distinct nuclei as amphibians and reptiles are examined, and they are as extensive in birds as they are in mammals. Some of the same neurohormones that are found in humans have been identified in nonmammals, and these neurohormones produce similar effects on cells of the pituitary as described above for mammals.

Neurosecretory centres

Two or more neurohormonal peptides with chemical and biologic properties similar to those of mammalian oxytocin and vasopressin are secreted by the vertebrate hypothalamus (except in Agnatha fishes, which produce only one). The oxytocin-like peptide is usually isotocin (most fishes) or mesotocin (amphibians, reptiles, and birds). The second peptide is arginine vasotocin, which is found in all nonmammalian vertebrates as well as in fetal mammals. Chemically, vasotocin is a hybrid of oxytocin and vasopressin, and it appears to have the biologic properties of both oxytocin (which stimulates contraction of muscles of the reproductive tract, thus playing a role in egg-laying or birth) and vasopressin (with either diuretic or antidiuretic properties). The functions of the oxytocin-like substances in nonmammals are unknown.

Tropic hormones

The pituitary glands of all vertebrates produce essentially the same tropic hormones: thyrotropin (TSH), corticotropin (ACTH), melanotropin (MSH), prolactin (PRL), growth hormone (GH), and one or two gonadotropins (usually FSH-like and LH-like hormones). The production and release of these tropic hormones are controlled by neurohormones from the hypothalamus. The cells of teleost fishes, however, are innervated directly. Thus, these fishes may rely on neurohormones as well as neurotransmitters for stimulating or inhibiting the release of tropic hormones.

Among the target organs that constitute the hypothalamic-pituitary-target organ axis are the thyroid, the adrenal glands, and the gonads. Their individual roles are discussed below.

The thyroid axis. Thyrotropin secreted by the pituitary stimulates the thyroid gland to release thyroid hormones, which help to regulate development, growth, metabolism, and reproduction. In humans, these thyroid hormones are known as triiodothyronine (T_3) and thyroxine (T_4). The evolution of the thyroid gland is traceable in the evolutionary development of invertebrates to vertebrates (Figure 5). The thyroid gland evolved from an iodide-trapping, glycoprotein-secreting gland of the protochordates (all nonvertebrate members of the phylum Chordata). The ability of many invertebrates to concentrate iodide, an important ingredient in thyroid hormones, occurs generally over the surface of the body. In protochordates, this capacity to bind iodide to a glycoprotein and produce thyroid hormones became specialized in the endostyle, a gland located in the pharyngeal region of the head.

The endostyle

From A. Gorbman and H. A. Bern, *Textbook of Comparative Endocrinology* (© 1963), by John Wiley & Sons, Inc.

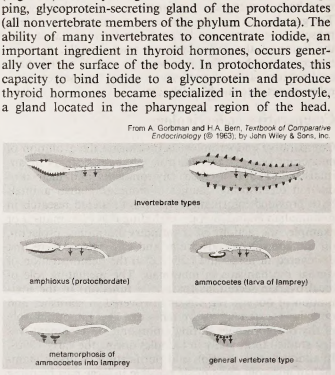


Figure 5: A summary of the known distribution of iodoproteins (shown as solid black) in the animal kingdom, suggesting a pattern of evolution of thyroid function.

When these iodinated proteins are swallowed and broken down by enzymes, the iodinated amino acids known as thyroid hormones are released. Larvae of primitive vertebrate lampreys also have an endostyle like that of the protochordates. When a lamprey larva undergoes metamorphosis into an adult lamprey, the endostyle breaks into fragments. The resulting clumps of endostyle cells differentiate into the separate follicles of the thyroid gland. Thyroid hormones actually direct metamorphosis in the larvae of lampreys, bony fishes, and amphibians. Thyroids of fishes consist of scattered follicles in the pharyngeal region. In tetrapods and a few fishes, the thyroid becomes encapsulated by a layer of connective tissue.

The adrenal axis. The adrenal axes in mammals and in nonmammals are not constructed along the same lines (Figure 6). In mammals the adrenal cortex is a separate structure that surrounds the internal adrenal medulla; the adrenal gland is located atop the kidneys. Because the cells of the adrenal cortex and adrenal medulla do not form separate structures in nonmammals as they do in mammals, they are often referred to in different terms; the cells that correspond to the adrenal cortex in mammals are called interrenal cells, and the cells that correspond to the adrenal medulla are called chromaffin cells. In primitive nonmammals the adrenal glands are sometimes called interrenal glands.

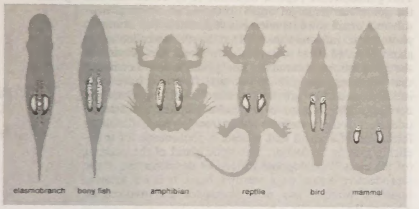


Figure 6: *Patterns of vertebrate adrenal glands.* White, interrenal or cortical tissue; black, chromaffin or medullary tissue; shaded area, kidney.

In fishes the interrenal and chromaffin cells often are embedded in the kidneys, whereas in amphibians they are distributed diffusely along the surface of the kidneys. Reptiles and birds have discrete adrenal glands, but the anatomical relationship is such that often the "cortex" and the "medulla" are not distinct units. Under the influence of pituitary adrenocorticotropin hormone, the interrenal cells produce steroids (usually corticosterone in tetrapods and cortisol in fishes) that influence sodium balance, water balance, and metabolism.

Gonadotropins

The gonadal axis. Gonadotropins secreted by the pituitary are basically LH-like and/or FSH-like in their actions on vertebrate gonads. In general, the FSH-like hormones promote development of eggs and sperm and the LH-like hormones cause ovulation and sperm release; both types of gonadotropins stimulate the secretion of the steroid hormones (androgens, estrogens, and, in some cases, progesterone) from the gonads. These steroids produce effects similar to those described for humans. For example, progesterone is essential for normal gestation in many fishes, amphibians, and reptiles in which the young develop in the reproductive tract of the mother and are delivered live. Androgens (sometimes testosterone, but often other steroids are more important) and estrogens (usually estradiol) influence male and female characteristics and behaviour.

Control of pigmentation. Melanotropin (melanocyte-stimulating hormone, or MSH) secreted by the pituitary regulates the star-shaped cells that contain large amounts of the dark pigment melanin (melanophores), especially in the skin of amphibians as well as in some fishes and reptiles. Apparently, light reflected from the surface stimulates photoreceptors, which send information to the brain and in turn to the hypothalamus. Pituitary melanotropin then causes the pigment in the melanophores to disperse and the skin to darken, sometimes quite dramatically. By releasing more or less melanotropin, an animal is able to adapt its colouring to its background.

Growth hormone and prolactin. The functions of growth hormone and prolactin secreted by the pituitary overlap considerably, although prolactin usually regulates water and salt balance, whereas growth hormone primarily influences protein metabolism and hence growth. Prolactin allows migratory fishes such as salmon to adapt from salt water to fresh water. In amphibians, prolactin has been described as a larval growth hormone, and it can also prevent metamorphosis of the larva into the adult. The water-seeking behaviour (so-called water drive) of adult amphibians often observed prior to breeding in ponds is also controlled by prolactin. The production of a protein-rich secretion by the skin of the discus fish (called "discus milk") that is used to nourish young offspring is caused by a prolactin-like hormone. Similarly, prolactin stimulates secretions from the crop sac of pigeons ("pigeon" or "crop" milk), which are fed to newly hatched young. This action is reminiscent of prolactin's actions on the mammary gland of nursing mammals. Prolactin also appears to be involved in the differentiation and function of many sex accessory structures in nonmammals, and in the stimulation of the mammalian prostate gland. For example, prolactin stimulates cloacal glands responsible for special reproductive secretions. Prolactin also influences external sexual characteristics such as nuptial pads (for clasping the female) and the height of the tail in male salamanders.

Functions of prolactin

Other vertebrate endocrine glands. *The pancreas.* The pancreas in nonmammals is an endocrine gland that secretes insulin, glucagon, and somatostatin. Pancreatic polypeptide has been identified in birds and may occur in other groups as well. Insulin lowers blood sugar (hypoglycemia) in most vertebrates, although mammalian insulin is rather ineffective in reptiles and birds. Glucagon is a hyperglycemic hormone (it increases the level of sugar in the blood).

In primitive fishes the cells responsible for secreting the pancreatic hormones are scattered within the wall of the intestine. There is a trend toward progressive clumping of cells in more evolutionarily advanced fishes, and in a few species the endocrine tissue forms only one or a few large islets. As a rule, most fishes lack a discrete pancreas, but all tetrapods have a fully formed exocrine and endocrine pancreas. The endocrine cells of all tetrapods are organized into distinct islets as described for humans, although the abundance of the different cell types often varies. For example, in reptiles and birds there is a predominance of glucagon-secreting cells and relatively few insulin-secreting cells.

Calcium-regulating hormones. Fishes have no parathyroid glands: these glands first appear in amphibians. Although the embryological origin of parathyroid glands of tetrapods is well known, their evolutionary origin is not. Parathyroid hormone raises blood calcium levels (hypercalcemia) in tetrapods. The absence in most fishes of cellular bone, which is the principal target for parathyroid hormone in tetrapods, is reflected by the absence of parathyroid glands.

Parathyroid glands

Fishes, amphibians, reptiles, and birds have paired pharyngeal ultimobranchial glands that secrete the hypocalcemic hormone calcitonin. The corpuscles of Stannius, unique glandular islets found only in the kidneys of bony fishes, secrete a peptide called hypocalcin. Fish calcitonins differ somewhat from the mammalian peptide hormone of the same name, and fish calcitonins have proved to be more potent and have a longer-lasting action in humans than human calcitonin itself. Consequently, synthetic fish calcitonin has been used to treat humans suffering from various disorders of bone, including Paget's disease (see below *The parathyroid glands: Metabolic bone disease*). The secretory cells of the ultimobranchial glands are derived from cells that migrated from the embryonic nervous system. During the development of a mammalian fetus, the ultimobranchial gland becomes incorporated into the developing thyroid gland as the "C cells" or "parafollicular cells."

Gastrointestinal hormones. Little research has been done on gastrointestinal hormones in nonmammals, but there is good evidence for a gastrinlike mechanism that controls the secretion of stomach acids. Peptides similar to cholecystokinin are also present and can stimulate contractions of the gall bladder. The gall bladders of primitive fishes contract when treated with mammalian cholecystokinin.

Other mammalian-like endocrine systems. *The renin-angiotensin system.* The renin-angiotensin system in mammals is represented in nonmammals by the juxtaglomerular cells that secrete renin associated with the kidney. The macula densa that functions as a detector of sodium levels within the kidney tubules of tetrapods, however, has not been found in fishes.

The pineal complex. In fishes, amphibians, and reptiles, the pineal complex is better developed than in mammals. The nonmammalian pineal functions as both a photoreceptor organ and an endocrine source for melatonin. Effects of light on reproduction in fishes and tetrapods are mediated at least in part through the pineal, and it has been implicated in a number of daily and seasonal biorhythmic phenomena.

Pineal functions

Prostaglandins. Many tissues of nonmammals produce prostaglandins that play important roles in reproduction similar to those discussed for humans and other mammals.

The liver. As in mammals, the liver of several nonmammalian species has been shown to produce somatomedin-like growth factors in response to stimulation by growth hormone. Similarly, there is evidence that prolactin stimulates the production of a related growth factor, which synergizes (cooperates) with prolactin on targets such as the pigeon crop sac.

Unique endocrine glands in fishes. In addition to the corpuscles of Stannius and the ultimobranchial glands, most fishes have a unique neurosecretory neurohemal organ, the urophysis, which is associated with the spinal cord at the base of the tail. Although the functions of this caudal (rear) neurosecretory system are not now understood, it is known to produce two peptides, urotensin I and urotensin II. Urotensin I is chemically related to a family of peptides that includes somatostatin; urotensin II is a member of the family of peptides that includes mammalian corticotropin-releasing hormone (CRH). There are no homologous structures to either the corpuscles of Stannius or the urophysis in amphibians, reptiles, or birds.

INVERTEBRATE ENDOCRINE SYSTEMS

Advances in the study of invertebrate endocrine systems have lagged behind those in vertebrate endocrinology, largely due to the problems associated with adapting investigative techniques that are appropriate for large vertebrate animals to small invertebrates. It also is difficult to maintain and study appropriately some invertebrates under laboratory conditions. Nevertheless, knowledge about these systems is accumulating rapidly.

Problems in invertebrate studies

All phyla in the animal kingdom that have a nervous system also possess neurosecretory neurons. The results of studies on the distribution of neurosecretory neurons and ordinary epithelial endocrine cells imply that the neurohormones were the first hormonal regulators in animals. Neurohemal organs appear first in the more advanced invertebrates (such as mollusks and annelid worms), and endocrine epithelial glands occur only in the most advanced phyla (primarily Arthropoda and Chordata). Similarly, the peptide and steroid hormones found in vertebrates are also present in the nervous and endocrine systems of many invertebrate phyla. These hormones may perform similar functions in diverse animal groups. With more emphasis being placed on research in invertebrate systems, new neuropeptides are being discovered initially in these animals, and subsequently in vertebrates.

The endocrine systems of some animal phyla have been studied in detail, but the endocrine systems of only a few species are well known. The following discussion summarizes the endocrine systems of five invertebrate phyla and the two invertebrate subphyla of the phylum Chordata, a phylum that also includes Vertebrata, a subphylum to which the backboned animals belong.

Phylum Nemertea. Nemertine worms are primitive marine animals that lack a coelom (body cavity) but differ from other acoelomates (animals that lack a coelom) by having a complete digestive tract. Three neurosecretory centres have been identified in the simple nemertine brain; one centre controls the maturation of the gonads, and all three appear to be involved in osmotic regulation.

Phylum Annelida. The cerebral ganglion (brain) of *Nereis,* a marine polychaete worm, produces a small peptide hormone called nereidine, which apparently inhibits precocious sexual development. There is a complex just beneath the brain that functions as a neurohemal organ. The epithelial cells found in this complex may be secretory as well, but this has not been proved. Neurohormones are released from the infracerebral complex into the coelomic fluid through which they travel to their targets. In the lugworm, *Arenicola,* there is evidence for a brain neuropeptide that stimulates oocyte maturation.

Phylum Mollusca. Within the phylum Mollusca, the class Gastropoda (snails, slugs) has been studied most extensively. The cerebral ganglion (brain) of several species (*e.g., Euhadra peliomorpha, Aplysia californica,* and *Lymnaea stagnalis*) secretes a neurohormone that stimulates the hermaphroditic gonad (the reproductive gland that contains both male and female characteristics); hermaphroditism is a common condition among mollusks. This gonadotropic peptide hormone (a hormone that has the gonads as its target organ) is stored in a typical neurohemal organ until its release is stimulated. For example, phototropic information detected by the so-called optic gland (located near the eye) can direct the release of the gonadotropic hormone. The gonadotropic hormones that cause egg laying in *Aplysia* and *Lymnaea* have been isolated, and they are very similar small peptides. The hermaphroditic gonad of *Euhadra* secretes testosterone (identical to the vertebrate testosterone), which stimulates formation of a gland that releases a pheromone for influencing mating behaviour. The optic gland of the octopus (of the class Cephalopoda) influences development of the reproductive organs on a seasonal basis. It is not known, however, whether any neurohormones are involved or whether this is purely a neurally controlled event.

The hermaphroditic gonad

Phylum Arthropoda. The arthropods are the largest and most advanced group of invertebrate animals, rivaling and often exceeding the evolutionary success of the vertebrates. Indeed, the arthropods are the most successful ecological competitors of humans. There are several major subdivisions, or classes, within the phylum Arthropoda, with the largest being Insecta (insects), Crustacea (crustaceans, including crabs, crayfishes, and shrimps), and Arachnida (arachnids, including the spiders, ticks, and mites). Even within these major classes, few species have been studied. Those that have been studied are large insects (*e.g.,* cockroaches, grasshoppers, and cecropia moths) and crustaceans.

The organizations of arthropod endocrine systems parallel those of the vertebrate endocrine system. That is, neurohormones are produced in the arthropod brain (analogous to the vertebrate hypothalamus) and are stored in a neurohemal organ (like the vertebrate neurohypophysis). The neurohemal organ of insects may have an endocrine portion (like the vertebrate adenohypophysis), and hormones or neurohormones released from these organs may stimulate other endocrine glands as well as nonendocrine targets. A general description of the endocrine systems of insects and crustaceans is given below.

Endocrine system organization

Class Insecta. Neurosecretory, neurohemal, and endocrine structures are all found in the insect endocrine system (Figure 7). There are several neurosecretory centres in the brain, the largest being the pars intercerebralis. The paired corpora cardiaca (singular, corpus cardiacum) and the paired corpora allata (singular, corpus allatum) are both neurohemal organs that store brain neurohormones, but each has some endocrine cells as well. The ventral nerve cord and associated ganglia also contain neurosecretory cells and have their own neurohemal organs; *i.e.,* the multiple perisympathetic organs located along the ventral nerve cord. The insect endocrine system produces neurohormones as well as hormones that control molting,

diapause, reproduction, osmoregulation, metabolism, and muscle contraction (Table 2).

Table 2: Processes in Insects Controlled by Neuropeptides of the Brain and/or Ventral Cord

Molting
Diapause
Sexual differentiation
Vitellogenesis
Sexual behaviour
Egg laying
Metabolism
Water and salt regulation
Heart rate
Rhythms in activity levels
Colour changes

Molting. A peptide neurohormone that controls molting is secreted by the pars intercerebralis and is stored in the corpora cardiaca or corpora allata (depending on the group of insects). This brain neurohormone is known as the prothoracotropic hormone (PTTH), and it stimulates the prothoracic glands (also called ecdysial or molting glands). In turn, the prothoracic glands release the steroid ecdysone, which is the actual molting hormone. Ecdysone initiates shedding of the old, hardened cuticle (exoskeleton).

Prothoracotropic hormone

In the 1940s Sir Vincent (Brian) Wigglesworth discovered that distention of the abdomen of the blood-sucking hemipteran bug *Rhodnius prolixus* following consumption of a blood meal sends neural impulses to the brain and triggers the release of PTTH. A similar mechanism has been found in a herbivorous (plant-eating) hemipteran as well. Size seems to trigger molting in lepidopterans (moths, butterflies), although the mechanism is not understood. Each molt is aided by a small amount of juvenile hormone (JH) secreted by endocrine cells of the corpora allata. Without JH during a critical time of the intermolt period of the last larval stage, either a pupa stage (diapause, or a resting state) or an adult stage is achieved. Juvenile hormone also keeps the epidermis in a larval state and causes it to secrete larval cuticle. Without JH, the epidermis changes and secretes the adult cuticle type. Three different closely related forms of JH have been isolated from seven major insect orders.

From (top) *Structure and Function in the Nervous Systems of Invertebrates* by Theodore Holmes Bullock and G. Adrian Horridge. W.H. Freeman and Company. copyright © 1965; (bottom) A. Gorbman and H.A. Bern. *Textbook of Comparative Endocrinology* (© 1963), by John Wiley & Sons, Inc.

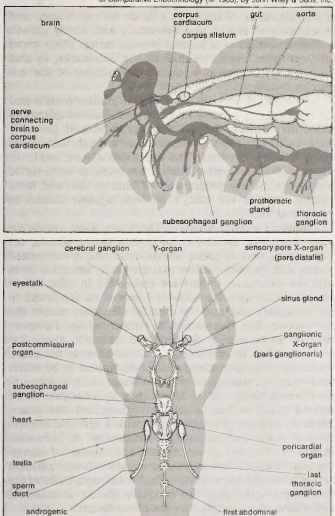


Figure 7: *Invertebrate endocrine systems.*
(Top) Central nervous and endocrine structures of a generalized insect; (bottom) endocrine system of a generalized male crustacean.

Diapause. Some insects enter diapause during development. Diapause is characterized by cessation of development or reproduction, decrease in water content (dehydration), and reduction in metabolic activities. It usually is preceded by an accumulation of nutrients resulting in hypertrophy of the fat bodies. Environmental factors (such as temperature, photoperiod, and food availability) cause storage of neurohormones, and the corpora allata become inactive. Termination of diapause can be brought about by reversing the environmental conditions that induced the diapause. Although juvenile hormone can terminate diapause, it triggers diapause in some insects. The stage of the life history may be important in determining the role of JH. For example, in imaginal diapause (characterized by cessation of reproduction in the imago, or adult), the absence of JH initiates diapause. In lepidopterans, a peptide that initiates diapause has been isolated from the subesophageal ganglion.

Effect of environmental factors

Reproduction. In some insects the pars intercerebralis secretes a neurohormone that stimulates vitellogenesis by the fat body (vitellogenesis is the synthesis of vitellogenin, a protein from which the oocyte makes the egg proteins). This neurohormone is stored in either the corpora cardiaca or the corpora allata, depending on the species. Uptake of vitellogenin by the ovary is enhanced by JH. In most insects, JH also stimulates vitellogenin synthesis by the fat body. There is evidence that other neurohormones secreted by the pars intercerebralis also influence reproduction. Some induce other tissues to secrete pheromones that influence reproductive behaviour of other individuals. In the live-bearing tsetse fly, *Glossina*, a neurohormone released from the corpora allata stimulates milk glands that provide nourishment to the developing larvae.

Osmoregulation. All insects produce a diuretic hormone and many produce an antidiuretic hormone as well. Insects feeding exclusively on a liquid diet (such as plant sap or blood) have only the diuretic hormone that allows them to eliminate excess fluid and salts through the malpighian tubules (the insect kidney). These osmoregulatory neurohormones are produced both in the brain and in the ventral nerve cord.

Myotropic and metabolic factors. One or more small peptide neurohormones are produced in the brain and ventral nervous system and are stored in the corpora cardiaca and perisympathetic organs, respectively. These myotropic factors stimulate heart rate as well as contractions of the kidney tubules and digestive tract. The corpora cardiaca were named for the heart-stimulating action produced by extracts of these organs. The glandular portion of the corpora cardiaca is thought to secrete the hyperglycemic hormone that causes a rapid increase in blood levels of trehalose, the "blood sugar" of insects. It is sometimes called the hypertrehalosemic hormone. This hypoglycemic hormone apparently is identical to the myotropic factors in at least one species, the American cockroach. An adipokinetic neurohormone released from the orthopteran corpora cardiaca (locusts, grasshoppers) causes the release of diglycerides into the blood during, and immediately after, flight. It is a peptide similar to the myotropic factors.

Class Crustacea. Among the crustaceans, the major neuroendocrine system consists of the neurosecretory X-organ and its associated neurohemal organ, the sinus gland. Both an X-organ and a sinus gland are located in each eyestalk, and together they are termed the eyestalk complex. Two endocrine glands are well known: the Y-organ and the androgenic gland (see Figure 7). As in insects, hormones and neurohormones of the crustacean regulate molting, reproduction, osmoregulation, metabolism, and

heart rate. In addition, the regulation of colour changes is well developed in crustaceans, whereas only a few insects exhibit hormonally controlled colour changes.

Molting. The steroid ecdysone secreted from the Y-organ stimulates molting. After it is released into the blood, ecdysone is converted to a 20-hydroxyecdysone, which is the active molting hormone. Secretion of ecdysone is blocked by a neurohormone called molt-inhibiting hormone, produced by the eyestalk complex. The existence of several additional molting factors has been proposed from experimental studies, and the regulation of molting may be much more complicated than suggested here.

Reproduction. The eyestalk complex appears to produce a neurohormone that inhibits vitellogenesis by the fat body and blocks vitellogenin uptake by oocytes in the ovary. Older follicles in the ovary, however, may secrete a vitellogenin-stimulating hormone that overrides the effects of the eyestalk neurohormone. In shrimps and other crustaceans that exhibit sequential hermaphroditism, the androgenic gland produces a peptide hormone that is necessary to masculinize the gonad. These animals function first as males, and later with the degeneration of the androgenic gland they become females. Surgical removal of the androgenic gland causes a precocious change of a male to a female.

Osmoregulation. There are four known sources of factors that influence water and ionic balance (osmoregulation) in crustaceans. The brain factor is known to regulate function of the antennal glands (paired "kidneys" located at the base of each antenna), the intestine, and the gills. The thoracic ganglion factor affects the stomach, intestine, and gills. Both the antennal glands and the gills are affected by a factor from the eyestalk complex. Finally, the pericardial organs (neurohemal glands located in the pericardial cavity) influence salt and water metabolism by heart muscle and gills.

Myotropic factor. Heart rate is accelerated in crustaceans by a factor released from the pericardial organs. It is not known if this factor is the same one that has osmoregulatory actions mentioned above. There is evidence to suggest that the crustacean cardioacceleratory factor is identical to one of the insect cardioacceleratory factors.

Colour changes. Several neurohormones that regulate colour changes (chromatophorotropins) by pigment cells (chromatophores) have been found in extracts of the eyestalk complex. The best known are the light-adapting hormone and the red-pigment-concentrating hormone. This latter peptide is chemically similar to the insect adipokinetic and myotropic factors. Regulation of the chromatophores allows an animal to adapt to different backgrounds by changing colours or by becoming lighter or darker.

Phylum Echinodermata. Female sea stars (starfishes) are the only echinoderms that have been studied extensively. A neuropeptide called the gonad-stimulating substance (also called the gamete-shedding substance) is released from the radial nerves into the body cavity about one hour before spawning. Gonad-stimulating substance has been reported in more than 30 species of sea star. This neuropeptide contacts the ovaries directly and causes formation of 1-methyladenine, an inducer of oocyte maturation and spawning. This same hormone has been demonstrated in the ovaries of the closely related sea urchin, where it also promotes maturation of the oocyte.

Gonad-stimulating substance

Phylum Chordata. The phylum Chordata is separated into three subgroups (or subphyla). The invertebrate subphylum Tunicata consists of the marine tunicates, including the ascidians and salps. The invertebrate subphylum Cephalochordata includes the fishlike amphioxus (or lancelet). Amphioxus is a small marine animal that closely resembles the larva of the jawless fishes (class Agnatha). The subphylum Vertebrata is the largest chordate subgroup.

Subphylum Tunicata. The ascidians (also called sea squirts) have a tadpolelike larva that lives free for a short period. The larva eventually attaches itself to a solid substrate and undergoes a marked metamorphosis into the sessile adult sea squirt. The larva and adult have a mucus-secreting gland, the endostyle, that is believed to be the evolutionary ancestor of the vertebrate thyroid gland. Metamorphosis in ascidians can be induced by application of thyroid hormones.

Neurosecretory neurons in the cerebral ganglion (brain) contain the vertebrate peptide gonadotropin-releasing hormone (GnRH). Directly adjacent to the brain is the neural (or subneural) gland that may be the forerunner of the vertebrate pituitary gland. Extracts prepared from ascidian neural glands stimulate testicular growth in toads, demonstrating the presence of a gonadotropic factor in the neural gland. A protein similar to human prolactin has been found in the neural gland of *Styela plicata.*

Subphylum Cephalochordata. The cephalochordate brain contains neurosecretory neurons that possibly are related to a structure called Hatschek's pit, located near the brain. Hatschek's pit appears to be related to the neural gland and hence to the vertebrate pituitary gland. Treatment of amphioxus with GnRH or luteinizing hormone (LH) reportedly stimulates the onset of spermatogenesis in male gonads. Furthermore, extracts prepared from Hatschek's pit can stimulate the testis of a toad. Amphioxus has a mucus-secreting endostyle like that of the ascidians, and studies have shown that the cephalochordate endostyle can synthesize thyroid hormones, too. Thus, the basic organization of the vertebrate endocrine system appears to show its early beginnings in the simple organs of these invertebrate chordates. (D.O.N.)

Hatschek's pit

The human endocrine system

GENERAL ASPECTS

Integrative functions. The endocrine systems of humans and other animals serve an essential integrative function. Inevitably, humans are beset by a variety of insults, such as trauma, infection, tumour formation, genetic defects, and emotional damage. The endocrine glands play a key role in responding to these stressful stimuli. Less obvious are the effects of subtle changes in the concentrations of key elements of the body's fluids on the storage and expenditure of energy and the steady and timely growth and development of a normal human being. These more subtle changes largely result from the monitoring by and the response, sometimes minute by minute, of the endocrine system.

The menstrual cycle in the normal, mature female and the reproductive process in males and females are under endocrine control. Beyond this, lactation and probably some forms of parental behaviour are strongly influenced by endocrine secretions. The endocrine system works in concert with the nervous and the immune systems to permit the orderly progression of human life, and these systems provide the body's bulwark against threats to health and life.

Control of endocrine system

Anatomical considerations. There are some characteristics shared by all endocrine glands. Some glands, for example the thyroid gland, are discrete, readily recognized organs with defined borders that are easily separable from adjacent structures. Others are embedded in other structures (for example, the islets of Langerhans are found in the pancreas) and may be clearly seen only under the microscope. The boundaries of endocrinology, however, have yet to be sharply defined, and endocrine tissue has been identified in surprising locations, such as the heart. Under the microscope, endocrine cells appear to be rather homogeneous, usually cuboidal in shape, with a rich supply of small blood vessels. Sometimes, as is the case in the thyroid gland, endocrine cells are intermixed with other, distinctly different endocrine cells with a different embryological origin and an entirely different set of hormonal secretions. Finally, all nerve cells are capable of secreting neurotransmitters into the synapses between adjacent nerves, although some nerve cells, for example those of the neurohypophysis (posterior pituitary gland), also secrete neurohormones directly into the bloodstream.

Endocrine glands with mixed cell populations have not evolved by chance. The hormonal secretions of one set may modulate directly the activity of adjacent cells with different characteristics. This direct action on contiguous cells of different types, which diffuses the hormone to tar-

Paracrine function

get cells without moving it through the general circulation, is known as paracrine function. Even in homogeneous glandular tissues (*i.e.,* tissues comprising one cell type), the direct proximity of the cells in some way enhances the amount of hormonal secretions since isolated cells are less vigorous in their activity, under laboratory conditions, than are sheets of attached cells, a phenomenon known as autocrine function. On the other hand, hormonal secretions themselves inhibit further hormonal secretion if they remain in the vicinity of the parent cell.

When viewed under the ultramicroscope (a microscope of extraordinary magnifying power), the endocrine cell has the fine structure that is illustrated in Figure 8. Many of the various intracellular structures, called organelles, are involved in the sequence of events that occurs during the synthesis and secretion of hormones.

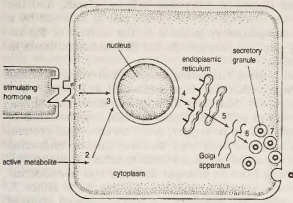


Figure 8: Intracellular structure of a typical endocrine cell.

Hormone synthesis. In the case of protein hormone synthesis, the target cell is stimulated at the cell surface (1 and 2) either by contact of a surface receptor with a stimulating hormone or by the entrance of a stimulating metabolite, such as glucose entering an insulin-producing beta cell. (It is important to note that there are also hormones and metabolites that lead to the inhibition of cell activity, but these are not discussed here.) Stimulation of the receptor at the cell surface is followed by a series of complex events within the cell membrane itself as well as within the cytoplasm of the cell. These events lead to the stimulation of DNA within the nucleus of the cell (3) to synthesize mRNA (messenger ribonucleic acid), which directs the synthesis of protein or steroid hormones.

Synthesis of mRNA

The mRNA unit contains the genetic code for the new protein. When mRNA leaves the nucleus and associates with the endoplasmic reticulum (4) in the cytoplasm, it directs the synthesis of a relatively inert precursor to the hormone, called a prohormone, from free amino acids available within the cytoplasm. The prohormone is sent to another cell organelle (5), the Golgi apparatus, where it is packaged into vesicles known as secretory granules (6). The granules migrate to the cell surface (7), and through a process known as exocytosis (8) the active hormone splits from the prohormone and is discharged through the cell wall.

In the case of steroid hormones, the precursor of all steroid hormones, cholesterol, is stored in vesicles within the cytoplasm. Through the actions of enzymes at various steps along the synthetic pathway, cholesterol is broken down and converted into steroid hormones.

Cholesterol is converted into pregnenolone in the first step of steroid biosynthesis. This action is the result of the cleaving enzyme that has been stimulated into action by corticotropin (ACTH) or angiotensin (which stimulate the adrenals), or the gonadotropins (hormones, such as LH and FSH, that stimulate the gonads). Pregnenolone is transported out of the mitochondria (where this initial step took place) to the endoplasmic reticulum (4), where it undergoes further enzymatic degradation to progesterone. At this point depending on the tissues in which the synthesis took place, progesterone is converted to the sex hormones (androgens and estrogens) or to the corticoids, mineralocorticoids, or adrenal androgens (steroid hormones of the adrenal cortex).

Regulatory mechanisms. Hormonal levels in the circulating body fluids vary in response to stimulatory or inhibitory influences acting on the hormone-producing cell. In the normal individual examined in a resting state, all circulating hormonal levels will be found to lie within a narrow normal range. Constant monitoring of hormonal supply to the tissues is essential to health, since sustained, inappropriate elevations or depressions of these levels will lead, in most instances, to disease states. Furthermore, since hormones are constantly being inactivated by tissue enzymes, the supply of hormones must be replenished regularly within the cell by synthesis and secretion.

Control of hormonal levels

The control of hormonal levels is maintained by a number of feedback devices. For target organs such as the thyroid, adrenal glands, and gonads, which also serve as endocrine glands, the hypothalamic-pituitary-target organ axis serves admirably. Other more direct feedback mechanisms, however, also operate (see Figure 2), for example, the stimulatory effect of low serum calcium levels on parathyroid glands and the stimulatory effect of elevated blood glucose levels on the beta cells of the islets of Langerhans. In another method of hormonal regulation, the metabolism of hormones after their secretion may either intensify or decrease hormonal action; for example, thyroxine may be converted in a number of tissues to triodothyronine (T_3), a change that enhances hormonal potency by 2½ times. Alternatively, T_4 may be converted to an inactive isomer (a molecule with the same atoms but with small, biologically important differences in structure) of T_3 (reverse T_3). Finally, local effects may significantly modulate endocrine cell activity. For most endocrine cells, if the secreted hormone remains in the immediate vicinity of the cell, further synthesis of the hormone is strongly inhibited. This effect supplements the autocrine and paracrine effects on adjacent cells of a tissue.

Modes of transport. Most hormones are secreted into the general circulation to exert their effects on appropriate distant target tissues. There are important exceptions, however, in the case of self-contained portal circulations in which blood is directed to specific areas. A portal circulation begins in a capillary bed, forms into a set of veins, and then is dispersed into a second capillary bed. Thus, blood collected from the first capillary bed is directed solely into the tissues nourished by the second capillary bed.

Two portal systems

Two such portal circulations are present in the human body. One system, the hypothalamic-hypophyseal portal circulation, collects blood from capillaries originating in the hypothalamus and, through a plexus of veins surrounding the pituitary stalk, directs the blood into the substance of the anterior pituitary. In this instance, hormones secreted by the neuroendocrine cells of the hypothalamus are transported directly, via this circulatory system, to modulate the activity of the endocrine cells of the anterior pituitary. These hormones are largely, but not entirely, excluded from the general circulation. In a second system, the hepatic portal system, capillaries originating in the gastrointestinal tract and the spleen are transported through veins by way of the hepatic vein into the liver and again dispersed into hepatic capillaries. In this way hormones from the pancreatic islets of Langerhans, such as insulin and glucagon, are directed into the substance of the liver in high concentration before being distributed through the general circulation.

Carrier proteins

A further refinement in hormone transport is provided by circulating carrier proteins. These substances, manufactured and secreted by the liver, provide sites to which steroid and thyroid hormones are bound. Carrier proteins include the binding globulins that bind sex hormones from the gonads, and transcortin, to which hormones from the adrenal cortex are bound. In addition, there are two sets of proteins, the prealbumins and the thyroxine-binding globulins, which transport the thyroid hormones, T_4 and T_3. Furthermore, there is evidence that other protein hormones, such as growth hormone, also are bound to specific transport proteins. Indeed, it is the rule that important biologic substances are bound to specific carrier proteins as they course through the circulation.

Protein-bound hormones are in equilibrium with a much smaller concentration of free circulating hormones. As a free hormone leaves the circulation to exert its action on a tissue, an equal amount of hormone is immediately freed

from its binding protein. Thus, the carrier proteins serve as a depot within the bloodstream to maintain a normal concentration of the biologically important free hormone. A final refinement of this system is that the concentration of carrier proteins is similarly hormone-dependent. Estrogens are known to increase the secretion and concentration of essentially all carrier proteins, while androgens generally have an opposite effect.

The affinity of hormones for these binding proteins is not constant. The thyroid hormone T_4, for example, is far more tightly bound than is the hormone T_3, with the result that T_3 is more readily released as a free molecule and has easier access to tissues. Similarly, some drugs, such as phenytoin (Dilantin), have a molecular configuration that permits them to compete with thyroxine for binding to thyroxine-binding globulin. When present in high concentrations, such a drug may successfully displace the level of bound hormones in the blood.

Biorhythms. Some hormones, for example insulin, are secreted in brief spurts every few minutes. Presumably, the time between spurts is a reflection of the lag time necessary for the insulin-secreting cell to sense a change in blood sugar concentration. Other hormones, particularly those of the pituitary, are secreted in pulses that may occur at roughly hourly intervals. Apparently, pulsated secretion is a necessary requirement for pituitary gonadotropin secretion. When stimulated at about 80-minute intervals by the injection of a hypothalamic gonadotropin-releasing hormone (GnRH), pituitary gonadotropin secretion increases incrementally to high levels. If, however, gonadotrophs are subjected to a continuous, nonpulsatile injection of GnRH, gonadotropin secretion is completely inhibited.

Circadian rhythms

Superimposed on these pulsatile secretions are, for many hormones, changes in hormonal levels that occur at roughly 24-hour intervals. These periodic changes are called circadian rhythms. An example is shown in Figure 9, which illustrates the circadian changes in the blood concentration of cortisol, the major steroid hormone secreted by the adrenal cortex. Low levels occur during sleep, with a rapid rise in the early morning hours, followed by a graduated descent during the day, with intermediate elevations during meal times. This particular rhythm is dependent on night-day cycles and persists for some days after jet-plane travel into different time zones. The transitional period is reflected in the well-known phenomenon of jet lag. Other hormones follow other circadian rhythms. Pituitary growth hormone, prolactin, and the gonadotropins rise to their highest diurnal (daily) levels shortly after the onset of sleep and, in the case of gonadotropins, this sleep-related elevation is the first biochemical sign of the onset of puberty.

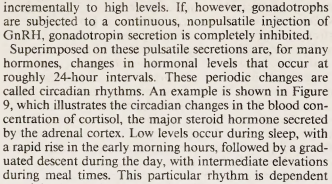


Figure 9: Circadian rhythm, a graphic depiction of cortisol values over a 24-hour period.

Monthly biorhythms are reflected in women in the menstrual cycle. Less obvious are seasonal cycles that occur in the secretion of thyroid hormones and testosterone. Finally, puberty itself is a complex, timed phenomenon that is thought to be associated with a reduction in secretion of melatonin, a hormone secreted by the pineal gland. This gland serves a regulatory function for many of the biorhythms, particularly those related to gonadal function.

ENDOCRINE DYSFUNCTION

Endocrine hypofunction and receptor defects. There are occasions when the body is best served by reducing the amount of hormone secreted by an endocrine gland (hypofunction). For example, the secretion of thyroid hormones decreases with protracted fasting. Because the thyroid hormones control energy expenditure, there is survival value in slowing the body's metabolism when there is no intake of food. Thus, there is a distinction between compensatory endocrine hypofunction and true endocrine dysfunction. Only those forms of hypofunction that reflect disease states are discussed in general terms below. Detailed descriptions of specific endocrine deficiency states are given in later sections devoted to each of the individual endocrine organs.

Destruction of endocrine cells

Endocrine glands may be destroyed in a variety of ways, but complete destruction is difficult. For most endocrine organs, at least 90 percent of the gland must be destroyed before a significant illness occurs. In the case of paired endocrine organs (parathyroids, adrenal glands, and the gonads) the removal of one of the pair is followed by a prompt compensatory increase in the activity of the remaining gland, so that an affected individual continues in good health.

Physical trauma (including surgical trauma and severe hemorrhage within the gland substance) may destroy any endocrine gland. Similarly, an invasion, known as infiltration, by cancer cells, inflammatory cells, large amounts of metal such as iron or copper, or by an abnormal protein, such as amyloid, may also seriously impair endocrine function. Bacterial infections (such as tuberculosis) and viral infections (such as mumps) also may lead to endocrine deficiencies. Although radiation damage from either X rays or radioactive elements is a well-recognized cause of hormonal deficiencies, both avenues have been adapted as forms of treatment when the problem is endocrine hyperfunction (excessive secretion by an endocrine gland).

Autoimmunity

Last, and perhaps most important, there is a growing understanding of an extraordinary phenomenon, known as autoimmunity, as a cause of endocrine deficiency. Certain antibodies generated by the body against its own tissues (see IMMUNITY), have been found to be active against certain endocrine tissues. Thus, not only are specific antibodies formed against specific endocrine glands, but there are also antibodies that affect specific aspects of endocrine function. For instance, in the case of the thyroid there are cytotoxic antibodies that eventually destroy the gland by attacking the cells; there are blocking antibodies that can, in effect, inactivate thyroid cell surface receptors and cause hypothyroidism; and there are stimulatory antibodies, which are a major cause of hyperthyroidism.

Constant exposure of an endocrine gland to blocking antibodies results in a reduction in its cell size and number, a condition known as atrophy. If long-lasting, atrophy may lead to irreversible destruction of the gland. Another cause of atrophy is a receptor defect that results when autoantibodies exert their actions against endocrine surface cell receptors. This kind of receptor damage has been found in females with premature ovarian failure associated with menopause, which can occur as early as the teenage years. It remains debatable whether a natural menopause is an example of hypofunction of the ovary, which should be viewed as pathological, or whether it represents another example of compensatory hypofunction with "survival value."

Endocrine atrophy is also associated with a number of forms of developmental failure, such as chromosomal abnormalities. For example, in Turner's syndrome, the Y chromosome of the two sex chromosomes, X and Y, is missing, resulting in the body configuration and orientation of a female despite the absence of functioning ovarian tissue. Another example is Klinefelter's syndrome, in which an extra X chromosome is added to the normal male complement of an X and a Y chromosome, leading to the development of an individual who appears as a feminized male and has some features of male hormone deficiency.

Secondary endocrine hypofunction

Secondary endocrine dysfunction is another distinct category of endocrine dysfunction, in which the gland is basically intact but lies dormant because it is either not stimulated or is directly inhibited. An important characteristic of this form of deficiency is that it is reversible, re-

turning to normal with the removal of the inhibiting agent. Secondary endocrine hypofunction results, for example, from the loss of a stimulating (tropic) hormone when the pituitary gland is completely destroyed. The loss of thyrotropin, corticotropin, and gonadotropins leads to hypofunction of the thyroid, adrenal, and gonads. Endocrine hypofunction may also occur as a result of exposure to excessive amounts of a hormone. In a patient taking large amounts of thyroid hormone the secretion of the thyroid-stimulating hormone thyrotropin by the anterior pituitary gland (see above *The nature of endocrine regulation*) will be inhibited, a change that puts the thyroid gland to rest.

Changes in the biochemical environment of the thyroid gland may also lead to a reduction in function. A well-known example is that of hypothyroidism due to iodine deficiency. Since iodine is an integral part of the thyroid hormone molecule, iodine deficiency leading to cretinism is common in those areas of the world in which salt contains little or no iodine. Drugs may also lead to a functional endocrine deficiency; such is the case in patients with manic-depressive psychosis treated with lithium, a drug that blocks thyroid gland activity. Finally, an excess of one hormone may lead to a deficiency of another. For example, overproduction of a pituitary hormone, prolactin, results in a secondary suppression of gonadal function, leading to amenorrhea in females and impotence in males. These changes are readily reversed when the level of prolactin in the bloodstream is returned to normal.

Iodine deficiency

Hormonal deficiency states can also occur from defective hormonal action on target organs. This concept was first proposed by an American clinical endocrinologist, Fuller Albright, and his associates in 1942. They studied a young woman who manifested all of the signs of deficiency of parathyroid hormone (PTH) but who, unlike the usual such patient, did not show any improvement after the injection of an extract of parathyroid gland. Albright termed this variant pseudohypoparathyroidism and postulated that "the disturbance is not a lack of PTH but an inability to respond to it." Direct evidence supporting this suggestion emerged only decades later, and other examples of unresponsiveness of target tissues to hormones have been documented. Thus, for example, an absence of receptors for male hormones makes individuals who are in genetic terms outwardly male appear to be female. Some diabetics do not respond to large quantities of insulin because they lack effective receptors in target cells for binding insulin. More common is resistance to insulin in diabetics due to the appearance of anti-insulin antibodies following insulin injections. Other antihormone antibodies may appear spontaneously and provoke endocrine deficiencies. Finally, there are rare instances in which hormone synthesis is abnormal so that the hormone secreted is chemically defective enough to impair its action on target tissues.

It should be noted that endocrine deficiencies may result from transmission of harmful materials from a mother to her fetus by way of the placenta. Toxic agents include autoantibodies and drugs, both of which cross the placenta readily and may damage the fetus even though, on occasion, the mother may remain unaffected.

The aging process

Because in many countries larger proportions of the populations are aging, an intensive search for the causes of aging processes has been instituted. An early popular theory was that aging resulted from multiple endocrine deficiencies. This idea has been discarded by most investigators. The only documented endocrine failure associated with age is the loss of ovarian hormones at the time of, and subsequent to, the menopause. Even here, however, the ovary continues to produce reduced amounts of estrogens. In general, endocrine function is highly variable in the aged. For most glands there is either no change or a modest reduction in endocrine secretions, but in the case of the pituitary gonadotropins, progressive gonad failure associated with aging results in pituitary hypersecretion (excessive secretion). Whether the changes observed have survival value is not known.

Endocrine hyperfunction. With excessive stimulation from any of a variety of causes, endocrine glands may become overactive, resulting in hypertrophy (increase in size of each cell) and hyperplasia (increase in cell numbers). The result is that the gland becomes enlarged. With continued stimulation, some undefined barrier is breached, and the hyperplastic glands undergo a transformation and begin uncontrolled multiplication of abnormal cells, termed neoplastic (tumorous). Because endocrine neoplasms are largely autonomous, they are far less sensitive to any inhibition of their hormonal secretions through negative feedback control. The result is that benign endocrine neoplasms (adenomas) persistently secrete excess hormone. Continued hyperstimulation causes some adenomas to undergo an additional change to a truly malignant neoplasm (a carcinoma), which is not only hyperfunctional but also is capable of invading adjacent structures and metastasizing (transferring) to distant organs, with the threat of causing death. Sometimes tumours of several endocrine glands occur simultaneously (see below *Ectopic hormone and polyglandular disorders*), which has been described as a syndrome (constellation of symptoms) called hereditary multiple endocrine neoplasia. It should also be noted, however, that many endocrine neoplasms produce no hormones whatsoever.

Neoplasms

Excess hormone secretion and the resultant symptoms may be produced by endocrine hyperplasia alone. One example of this occurs when a circulating autoantibody binds to receptors in the thyroid gland and causes the hypersecreting, hyperplastic thyroid typical of Graves' disease. Other syndromes of endocrine hyperfunction may result when a small endocrine tumour, innocuous in itself, secretes excessive amounts of a stimulatory hormone, which then provokes a secondary hyperplasia of a target gland. The classic instance is Cushing's disease, in which a small pituitary tumour produces excess quantities of adrenocorticotropin (ACTH) and leads to hyperplasia of both adrenal glands. The result is oversecretion of the hormones of the adrenal cortex, with striking consequences. A rare example of adenoma formation resulting from unremitting stimulation is found in patients with long-standing thyroid hormone deficiency. Through negative feedback mechanisms, the pituitary cells that secrete thyroid-stimulating hormone (TSH) become hyperplastic and eventually are transformed into TSH-producing adenomas of the pituitary.

Cushing's disease

Some endocrine tumours not only produce excess quantities of the expected hormone but also excess amounts of a hormone that is normally secreted by an entirely different endocrine gland. Thus, a medullary carcinoma of the thyroid originates from cells that normally produce calcitonin, a hormone which acts to lower the concentration of calcium in the blood. This tumour may hypersecrete not only calcitonin but also ACTH, normally a secretory product of cells of the pituitary gland. In addition, tumours arising from tissues that ordinarily have no endocrine function may secrete one or more hormones. A typical example is that of a cancer of the lung, which may produce one or more of an array of hormones, most commonly antidiuretic hormone. Such neoplasms are called ectopic (displaced) hormone-producing tumours.

The source of stimulation of hyperplastic glands is often known, as in the case of the parathyroid hyperplasia that follows persistently low levels of serum calcium in patients with severe kidney disease. In other instances, however, no cause has been identified; in these cases, the cause is said to be idiopathic. An example of idiopathic hyperplasia is the increase in the number of insulin-producing beta cells in the islets of Langerhans, which produces severe brain-damaging hypoglycemia (lowering of the blood sugar) in infants.

Some hormones exert their regulatory actions through an agonist/antagonist relationship to tropic hormones and receptor sites of the target cell. An agonist is a substance (for example, a hormone or a drug) that binds with specific receptors on target cells and elicits a response. An antagonist (also a hormone or drug) is a substance with a molecular structure similar enough to that of the agonist to compete with it and bind to the same specific receptors, although, once bound, it does not elicit a response. The actions of the antagonist hormone may modify the hypersecretion of the agonist hormone by binding with some of the available receptor sites, and the loss of an antagonist may

Agonists and antagonists

lead to effective hyperfunction of the agonist. An example is a person who has a deficiency of the adrenal cortex, which produces hormones that are sharply antagonistic to the action of insulin. When fasting or when injected with only a small amount of insulin, such individuals suffer the effects of severe hypoglycemia.

The general aspects of the human endocrine system discussed above may now be applied specifically in the more detailed discussion of individual endocrine glands.

THE HYPOTHALAMUS

Anatomy. The hypothalamus is an integral part of the substance of the brain. A small cone-shaped structure, it projects downward, ending in the pituitary (infundibular) stalk, a tubular connection to the pituitary gland. Figure 10 shows the relationship of these small structures in a lateral midline projection of the human head using the technique of magnetic resonance imaging. The round bony cavity containing the pituitary gland is called the sella turcica. The posterior portion of the hypothalamus, called the median eminence, contains many neurosecretory cells. Important adjacent structures include the mamillary bodies, the third ventricle, and the optic chiasm, the last being of particular concern to physicians because pressure from expanding tumours or inflammations in the hypothalamus or pituitary gland may result in severe visual defects or total blindness. Above the hypothalamus is the thalamus. (For discussion of the function of these surrounding structures, see NERVES AND NERVOUS SYSTEMS.)

Location

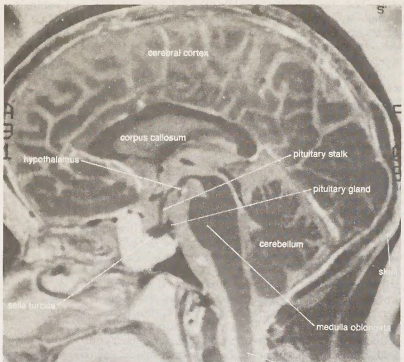


Figure 10: Cross-sectional photograph of the midline of the skull using magnetic resonance imaging. The glands within the brain and their physical interrelationships are illustrated (see text).

Regulation of hormone secretion. The hypothalamus, like the rest of the brain, consists of interconnecting nerve cells (neurons) with a rich blood supply. To understand hypothalamic function it is necessary to define the various forms of neurosecretion. First, there is neurotransmission, which occurs throughout the brain and is the process by which one nerve cell communicates with another at an intimate intermingling of projections from the two cells (a synapse). This transmission of an electrical impulse from one cell to another requires the secretion of a chemical substance from a long projection from one nerve cell body (the axon) into the synaptic space. The chemical substance that is secreted is called a neurotransmitter. The process of synthesis and secretion of neurotransmitters is similar to that shown in Figure 8 with the exception that neurosecretory granules migrate through lengths of the axon before being discharged into the synaptic space.

Neurologists have long been aware of four classical neurotransmitters: epinephrine, norepinephrine, serotonin, and acetylcholine, but recently there have emerged a large number of additional neurotransmitters, of which an important group is the neuropeptides. While bioamines and neuropeptides function as neurotransmitters, some of them also perform the role of neuromodulators; they do not act directly as neurotransmitters but rather as inhibitors or stimulators of neurotransmission. Well-known examples are the opioids (for example, enkephalins), so named because they are the naturally occurring peptides with a strong affinity to the receptors that bind opiate drugs such as morphine and heroin. In effect, they are the body's opiates.

Classical neurotransmitters

Thus the brain, and indeed the entire central nervous system, consists of an extraordinary network of neurons interconnected by neurotransmitters. The secretion of specific neurotransmitters, modified by neuromodulators, lends an organized, directed function to the overall system. These neural connections extend upward from the hypothalamus into other key areas, including the cerebral cortex. The result is that intellectual and functional activities as well as external influences, including stresses, can be funneled into the hypothalamus and thence to the endocrine system, from which they may exert effects on the body.

In addition to secreting neurotransmitters and neuromodulators, the hypothalamus synthesizes and secretes a number of neurohormones. The neurons secreting neurohormones are true endocrine (neurohemal) cells in the classical sense since secretory granules containing neurohormones travel from the cell body through the axon to be extruded, where they enter directly a capillary network, thence to be transported through the hypophyseal-portal circulation to the anterior pituitary gland.

Neurohormones

Finally, the neurohypophysis, or posterior lobe of the pituitary gland, provides the classical example of neurohormonal activity. The secretory products, mainly vasopressin and oxytocin, are extruded into a capillary network, which feeds directly into the general circulation.

The existence of hormones of the hypothalamus was predicted well before they were detected and chemically characterized, and they have been studied intensively by many investigators. Two groups of American investigators, led by Andrew Schally and Roger Guillemin, respectively, shared the Nobel Prize for Physiology or Medicine for 1977 for their research on pituitary hormones.

These neurohormones are known as releasing hormones because the major function generally is to stimulate the secretion of hormones originating in the anterior pituitary gland. They consist of simple peptides (chains of amino acids) ranging in size from only three amino acids (thyrotropin-releasing hormone) to 44 amino acids (growth hormone-releasing hormone).

Releasing hormones

Hormones. *Thyrotropin-releasing hormone.* Thyrotropin-releasing hormone (TRH), a neurohormone, is the simplest of the hypothalamic neuropeptides. It consists essentially of three amino acids in the sequence glutamic acid–histidine–proline. The simplicity of this structure is deceiving for TRH is involved in an extraordinary array of functions. Not only is it a neurohormone that stimulates the secretion of thyroid-stimulating hormone from the pituitary, and, quite independently, the secretion of another pituitary hormone called prolactin, but it also subserves other central nervous system activities because it is a widespread neurotransmitter or neuromodulator within the brain and spinal cord. There is evidence that TRH is involved in the control of body temperature and that it has psychological and behavioral effects, at least in animals. It may also have therapeutic value. There are studies suggesting that it mitigates the damage induced by spinal cord injury and that it leads to some improvement in the nervous disease known as amyotrophic lateral sclerosis (Lou Gehrig's disease).

These multiple effects are less surprising when it is considered that TRH appeared very early in the evolutionary scale of vertebrates and that, while the concentration of TRH is greatest in the hypothalamus, the total amount of TRH in the remainder of the brain far exceeds that of

the hypothalamus. The TRH-secreting cells are subject to stimulatory and inhibitory influences from higher centres in the brain and they also are inhibited by circulating thyroid hormone. In this way TRH forms the topmost segment of the hypothalamic-pituitary-thyroid axis.

Gonadotropin-releasing hormone. Gonadotropin-releasing hormone (GnRH), a neurohormone also known as luteinizing hormone-releasing hormone (LHRH), is a peptide chain of 10 amino acids. It stimulates the synthesis and release of the two pituitary gonadotropins, luteinizing hormone (LH) and follicle-stimulating hormone (FSH). While some investigators hold that there are two types of GnRH, most evidence supports the conclusion that only one type of neuropeptide stimulates the release of the two gonadotropins and that the variations in levels of both gonadotropins in the circulation are due to other modulating factors.

GnRH effects

Characteristic of all releasing hormones and most striking in the case of GnRH is the phenomenon of pulsatile secretion. In normal individuals, GnRH is released in spurts at intervals of about 80 minutes. The pulsatile administration of GnRH in large doses results in an ever-increasing concentration of gonadotropins in the blood. In striking contrast, the constant infusion of GnRH suppresses gonadotropin secretion. This phenomenon is advantageous for persons for whom suppression is important. Such persons include children with precocious puberty, and elderly men with cancer of the prostate. On the other hand, pulsatile administration of GnRH is efficacious in men or women in whom deficiency of gonadal function is due to impaired secretion of GnRH. A potential application of this phenomenon is the synthetic modifications of GnRH as a male as well as a female contraceptive.

Limbic system

Neurons that secrete GnRH have connections to an area of the brain known as the limbic system, which is heavily involved in the control of emotions and sexual activity. Studies in rats deprived of pituitary glands and ovaries but maintained on physiological amounts of female hormone (estrogen) have demonstrated that the injection of GnRH results in complex and striking changes in posture characteristic of the receptive female stance for sexual intercourse.

Some individuals have hypogonadism (in which the functional activity of the gonads is decreased and sexual development is inhibited) due to a congenital deficiency of GnRH, which responds to treatment with GnRH. Most of these people also suffer from hypothalamic disease and are deficient in other releasing hormones as well, but there are also individuals in whom GnRH deficiency is isolated and associated with a loss of the sense of smell (anosmia). Abnormalities in the pulses of GnRH secretion result in subnormal fertility, abnormal or absent menstruation, and possibly cystic disease of the ovary or even ovarian cancer.

Corticotropin-releasing hormone. Corticotropin-releasing hormone (CRH), a neurohormone, is a large peptide consisting of a single chain of 41 amino acids. It stimulates not only secretion of corticotropin in the pituitary gland but also the synthesis of corticotropin in the corticotropin-producing cells (corticotrophs) of the anterior lobe of the pituitary gland. Many factors, both neurogenic and hormonal, regulate the secretion of CRH, since CRH is the final common element directing the body's response to all forms of stress, whether physical or emotional, external or internal. (This key role of CRH in the hypothalamic-pituitary-adrenal axis is discussed below in connection with the adrenal gland.) Among the hormones that play an important role in modulating the influence of CRH is cortisol, the major hormone secreted by the adrenal cortex, which, as part of the negative feedback servomechanism (exerting control over another system through negative feedback), blocks the secretion of CRH. Vasopressin, the major regulator of the body's excretion of water, has an additional ancillary role in stimulating the secretion of CRH.

Cortisol

Excessive secretion of CRH leads to an increase in the size and number of corticotrophs in the pituitary gland, often resulting in a pituitary tumour. This, in turn, leads to excessive stimulation of the adrenal cortex, resulting in high circulating levels of adrenocortical hormones, the clinical manifestations of which are known as Cushing's syndrome. Conversely, a deficiency of CRH-producing cells can, by a lack of stimulation of the pituitary and adrenal cortical cells, result in adrenocortical deficiency. (These conditions are discussed below.)

Growth hormone-releasing hormone. Like CRH, growth hormone-releasing hormone (GHRH) is a large peptide. A number of forms have been described that differ from one another only in minor detail and in the number of amino acids (varying from 37 to 44). Unlike the other neurohormones, GHRH is not widely distributed in other parts of the brain. It is stimulated by stresses, including physical exercise, and secretion is blocked by a powerful inhibitor called somatostatin (see below *Somatostatin*). Negative feedback control of GHRH secretion is mediated largely through compounds called somatomedins, growth-promoting hormones that are generated when tissues are exposed to growth hormone itself.

An excess of circulating growth hormone in adults leads to a condition called acromegaly. Rarely, a benign tumour, called a hamartoma, located in the hypothalamus may produce excessive amounts of GHRH, leading to acromegaly. Equally rare are tumours arising in the islets of Langerhans of the pancreas that may secrete excessive quantities of GHRH. Indeed, GHRH was first successfully isolated and analyzed from such an ectopic (abnormally positioned) hormone-producing tumour. Isolated deficiency of GHRH (in which there is normal functioning of the hypothalamus except for this deficiency) may be the cause of one form of dwarfism, a general term applied to all individuals with abnormally small stature.

Acromegaly

Somatostatin. Somatostatin refers to a number of polypeptides consisting of chains of 14 to 28 amino acids. The name was coined when its discoverers found that an extract of the hypothalamus strongly inhibited the release of growth hormone from the pituitary gland. Somatostatin is also a powerful inhibitor of pituitary TSH secretion. Somatostatin, like TRH, is widely distributed in the central nervous system and in other tissues. It serves an important paracrine function in the islets of Langerhans, by blocking the secretion of both insulin and glucagon from adjacent cells. Somatostatin has emerged not only as a powerful blocker of the secretion of GH, insulin, glucagon, and other hormones but also as a potent inhibitor of many functions of the gastrointestinal tract, including the secretion of stomach acid, the secretion of pancreatic enzymes, and the process of intestinal absorption. Despite these multiple, widespread actions, the term somatostatin has persisted because of its major role as a regulator of GH secretion, and impaired somatostatin secretion may cause some forms of hypersecretion of growth hormone.

No examples of somatostatin deficiency have been found, but a tumour called a somatostatinoma has been well characterized in a number of patients. Persons with a somatostatinoma have cramping abdominal pain, persistent diarrhea, a mild elevation of blood glucose levels, and sudden flushing of the skin.

Prolactin-inhibiting and -releasing hormones. The hypothalamic regulation of prolactin secretion from the pituitary is different from the hypothalamic regulation of other pituitary hormones in two respects. First, the hypothalamus primarily inhibits rather than stimulates the release of prolactin from the pituitary (the hypothalamus stimulates the release of all other pituitary hormones). Thus, if pituitary cells are removed from the influence of the hypothalamus, few or none of the pituitary hormones are secreted, except for prolactin, which continues to be secreted by the prolactin-secreting cells (lactotrophs). Second, this major inhibiting factor is not a neuropeptide, but rather the neurotransmitter dopamine, a fact exploited in afflicted persons by physicians who are able to reduce abnormally high concentrations of prolactin by using drugs that mimic the prolactin-inhibiting effects of dopamine. Another prolactin-inhibiting factor (PRF) comes into play primarily during pregnancy and lactation. Prolactin-stimulating factors also exist, among them TRH.

Regulation of prolactin secretion

Prolactin deficiency is known to occur, but only rarely. Excessive prolactin production (hyperprolactinemia) is a common endocrine abnormality, and the prolactinoma is the most frequently encountered pituitary tumour.

Gastrointestinal neuropeptides. Although modern endocrinology began with the discovery that a substance, secretin, secreted into the blood from the cells lining the gastrointestinal tract stimulates the secretion of pancreatic juices, little attention was subsequently paid to gastrointestinal hormones. When investigators began to examine the distribution of neuropeptides within the body, however, there emerged a bewildering variety of these hormones, not only within the brain but also in the lining of the gastrointestinal tract and in other organs. The list includes glucagon, the enkephalins, secretin, cholecystokinin, gastrin, calcitonin, angiotensin, substance P, pancreatic polypeptide, neuropeptide Y (a human variant of a peptide called bombesin), delta-sleep-inducing peptide, and vasoactive intestinal peptide. The actions and interactions of these hormones both in the intestinal tract and in the brain are complex and are the subject of continuing investigations. Briefly, these peptides play important roles in the transmission and inhibition of pain stimuli, in eating and drinking behaviour, in memory and learning, in the regulation of body temperature, in the induction of sleep, and in sexual behaviour.

THE ANTERIOR PITUITARY

Anatomy. The pituitary gland lies at the base of the skull, nestled in a bony structure called the sella turcica. The gland is attached to the hypothalamus by the pituitary stalk, around and through which course the veins of the hypophyseal-portal plexus. In most species the gland is divided into three lobes: anterior, intermediate, and posterior. In humans the intermediate lobe does not exist as a distinct anatomic structure but rather remains only as dispersed cells. Despite its proximity to the anterior pituitary, the posterior lobe of the pituitary is functionally distinct and is an integral part of a separate neural structure called the neurohypophysis (see below *The posterior pituitary* [*neurohypophyses*]: *Neurohypophyseal unit*).

Pituitary lobes

The cells comprising the anterior lobe are derived embryologically from an extension of the roof of the pharynx, known as Rathke's pouch. While the cells appear to be relatively homogeneous (of the same type) under a light microscope, there are in fact five different types, each of which, except in pathological states, secretes the same hormone or hormones throughout its existence. The thyrotroph synthesizes and secretes thyrotropin (thyroid-stimulating hormone, or TSH); the gonadotroph, both LH and FSH; the corticotroph, corticotropin (also called adrenocorticotropic hormone, or ACTH); the somatotroph, somatotropin (also called growth hormone, GH); and the lactotroph, prolactin (PRL).

These hormones are proteins that consist of large polypeptide chains. Furthermore, the gonadotropins and TSH are glycoproteins in which there is linkage to carbohydrates known as polysaccharides. Each of these three hormones is composed of two glycopeptide chains; one of which, the alpha chain, is identical in all three hormones, while the other, the beta chain, differs in structure for each hormone, lending specificity for individual hormone action. As is the case in all protein hormones, hormones of the anterior pituitary are synthesized initially in the cytoplasm of the cell as larger, inactive molecules called prohormones, which are split into the active hormone molecules at the time of secretion into the circulation.

Alpha and beta chains

Hormones. *Thyrotropin.* Thyrotropin is also called thyroid-stimulating hormone (TSH). Thyrotropin-producing cells (thyrotrophs) make up about 10 percent of the anterior pituitary and are located mainly in the centre of the gland. Thyrotropin becomes attached firmly to receptors on the surface of the thyroid cells, forming thyroid follicles in the thyroid gland. Following binding, a complex train of events occurs so that preformed thyroid hormones are secreted and steps are set in motion for the synthesis of additional thyroid hormones. Thyrotropin exerts other pervasive effects. It stimulates the growth of thyroid cells and leads to increased blood flow through the gland. It also enhances the breakdown of thyroglobulin, a large thyroid-hormone-containing glycoprotein that is stored within the follicles of the thyroid gland.

The levels of thyrotropin in circulating fluids become elevated during thyroid hormone deficiency because there is no negative feedback inhibition of pituitary thyrotropin release by thyroid hormone. Elevated thyrotropin levels are found in other pathological states, including the presence of a thyrotropin-producing pituitary tumour. Low serum thyrotropin levels occur following damage to cells in the hypothalamus that produce thyrotropin-releasing hormone (TRH), following damage to the pituitary stalk, or, finally, following damage to the thyrotrophs themselves. Tests of increased sensitivity have made the measurement of thyrotropin in blood valuable in detecting subtle changes of both thyroid hyperfunction and hypofunction.

Levels of thyrotropin

Gonadotropins. Gonadotrophs, which amount to about 7 percent of all pituitary cells, secrete two hormones, luteinizing hormone (LH) and follicle-stimulating hormone (FSH), but not in equal amount. The rate of secretion varies widely at different ages and at different times in the menstrual cycle of the female. Secretion of LH and FSH is low before puberty in both sexes. After puberty, about five times more LH than FSH is secreted. During menstrual cycles there is a dramatic rise in both hormones at the time of ovulation (see below *The ovary*), and secretion increases as much as 15-fold following menopause.

In men FSH stimulates the development of spermatozoa, in large part by acting on special cells in the testes called Sertoli cells. In women FSH stimulates the synthesis of estrogens as well as the maturation of cells lining the spherical, egg-containing structures known as the Graafian follicles. In menstruating women, there is a preovulatory surge in FSH levels in the blood. Inhibin, a hormone secreted by the Graafian follicles of the ovary and the Sertoli cells of the testis, inhibits the secretion of FSH from the pituitary gonadotroph.

In men androgens (male hormones) are secreted by specialized cells called Leydig cells, a process stimulated by LH. In women a preovulatory surge of LH is essential for rupture of the Graafian follicle so that the egg can be discharged on its journey to the uterus. The empty follicle becomes filled with other, progesterone-producing cells, transforming it into a corpus luteum.

Leydig cells

When a disease process leads to encroachment on the cells of the pituitary gland, usually the first evidence of cell failure is in the gonadotroph. Thus, disappearance of menstrual periods may be the first sign of a pituitary tumour in the female. In the male the most common symptom of gonadotropin deficiency is impotence. Isolated deficiencies of both LH and FSH do occur, but only rarely. In a male, LH deficiency alone leads to the appearance of what has been described as a "fertile eunuch"; there is sufficient FSH present to permit the maturation of spermatozoa, but because of the LH deficiency the man has, nonetheless, many of the characteristics of a castrate. Tumours also can produce an excess of LH or FSH, and pituitary tumours that secrete only the nonspecific, hormonally inactive alpha unit of glycoprotein hormones are not rare.

Corticotropin. Corticotropin, also called adrenocorticotropin hormone (ACTH), is a segment of a much larger prohormone glycoprotein molecule called pro-opiomelanocortin, which is synthesized by pituitary corticotrophs. This prohormone is split into a number of biologically active polypeptide fragments when the secretory granule is discharged from the cell. Among these hormones are corticotropin, whose major action is to stimulate growth and secretion of the cells of the adrenal cortex; alpha- and beta-melanotropin (melanocyte-stimulating hormone, MSH), which increases pigmentation of the skin; beta-lipotropin (LPH), which stimulates the release of fatty acids from adipose tissue; a small fragment of ACTH thought to improve memory; and beta-endorphin, a polypeptide that has excited a good deal of popular as well as scientific interest (see below *The adrenal cortex*).

Beta-endorphins (along with the enkephalins, which are neuromodulators) were discovered when investigators postulated that, since opiates such as morphine bind firmly to cell-surface receptors, there must exist natural substances that do likewise and have a narcotic action. The endorphins and enkephalins are known, therefore, as endogenous (self-generated) opiates or opioids. They have

Endorphins and enkephalins

powerful painkilling properties. Beta-endorphins instilled in the spinal fluid are capable of alleviating otherwise intractable pain in cancer patients. It has often been observed that severely traumatized individuals, those in battle, for example, appear to be free of pain. This phenomenon is due to the simultaneous release of beta-endorphin along with corticotropin in response to the stressful stimulus of the injury. There have also been reports of children with endorphin-producing pituitary tumours who are highly insensitive to pain. In addition, the release of endorphin or enkephalin may account for the euphoria ("high") experienced by long-distance runners. Finally, there is evidence, not fully accepted, that endogenous opioids stimulate appetite. This is seen in rats and obese persons who have a rare disease called Prader-Labhart-Willi syndrome. In these instances, the appetite is diminished after the administration of a narcotic antagonist, such as naloxone.

Hyperplasia or adenoma of corticotrophs gives rise to the constellation of symptoms called Cushing's syndrome. A deficiency of corticotropin also occurs both as part of the multiple deficiencies of panhypopituitarism and as an isolated defect. The diagnosis of corticotropin deficiency is important because afflicted persons who are also subjected to stress can succumb to severe shock. Once frequently administered in the treatment of disorders including allergic states, collagen disorders, and autoimmune diseases, corticotropin has been largely displaced by a number of synthetic variants of adrenal steroids.

Growth hormone. Somatotrophs are plentiful in the pituitary, constituting 40 percent of the gland. They are located predominantly in the lateral lobes and secrete between one and two milligrams of growth hormone (GH; also called somatotropin) per day. Growth hormone stimulates growth, not only of bone but of essentially all the tissues of the body. In biochemical terms, growth hormone simultaneously stimulates protein synthesis in tissues and enhances the breakdown of fat to provide the energy for the stimulated growth. Growth hormone is also an insulin antagonist and, in susceptible individuals, can lead to elevated sugar levels in the blood and diabetes mellitus.

Effects of GH

While GH may act on tissues directly, much of its effect is mediated by way of stimulating the liver and other tissues to manufacture and release secondary hormones, called somatomedins, which partly mimic the action of insulin. During childhood, somatomedin levels in the serum rise progressively with age, with an accelerated increase occurring at the time of the growth spurt of puberty, followed by a reduction to adult levels.

Growth hormone secretion is stimulated by growth hormone-releasing hormone (GHRH; also known as somatocrinin) and is inhibited by somatostatin. There are prominent daily fluctuations in growth hormone secretion in normal individuals, with the largest increase occurring shortly after the onset of sleep. Again, this increase is most pronounced at the time of puberty. Growth hormone levels in the serum are elevated in individuals with tumours that produce growth hormone, and its levels are unresponsive to stimulation in states of malnutrition.

There are many causes of short stature or dwarfism (see below *Growth and development*) other than deficient growth hormone secretion; for example, chromosomal abnormalities, malnutrition (including poorly controlled diabetes mellitus), thyroid deficiency, and disorders of bone formation are all examples of dwarfism with normal GH secretion. Nonetheless, growth hormone deficiency is a fairly common cause of short stature. Perhaps most frequent is GH deficiency resulting from damage to the hypothalamus and pituitary during fetal development or at birth because of trauma, lack of oxygen, or any of a number of other causes. When damage to the hypothalamus or pituitary is mild, growth hormone deficiency may be the only detectable manifestation of a disease state because the somatotrophs are the most sensitive of the pituitary cells to injury. When all of the cells of the pituitary are severely damaged or destroyed the patient is said to have panhypopituitarism (leading to diminished function of the gonads, the thyroid, and the adrenal glands).

Midgets usually suffer from one of two forms of hereditary (familial) isolated growth hormone deficiency. In some families the deficiency is the result of underproduction of GHRH, in which case growth hormone secretion may be stimulated by infusion of GHRH. In others, the problem lies in the somatotrophs themselves when they become incapable of manufacturing growth hormone. Growth hormone levels also tend to fall in some aged persons who otherwise appear to be normal.

In other forms of dwarfism, the hypothalamus and pituitary function adequately, and the abnormality lies rather in the lack of response of body tissues. A well-studied example is that of the Laron dwarf. These children suffer from a hereditary disorder characterized by the inability of growth hormone to bind to specific receptors in the body's tissues; circulating GH levels are elevated but somatomedin levels remain low because GH, unable to bind to receptors, cannot stimulate somatomedin secretion. Another example is the African Pygmy, in whom there is a resistance to the administration of GH. This is caused by an unresponsiveness to somatomedin, which suggests that there is a defect in the somatomedin receptors.

Growth hormone alone cannot generate growth without an adequate supply of food, so that in states of malnutrition dwarfism occurs in the face of a mild elevation in growth hormone concentrations in the blood.

Finally, an example of the effect of emotional and environmental factors on growth is found in the condition known as psychosocial dwarfism. Such children suffer emotional deprivation from uncaring or abusive parents. Growth hormone levels are low but return to normal along with an increased rate of growth when the children are removed to a more supportive environment, only to have the cycle repeated when the child is returned to the custody of the parents. These victims tend to be withdrawn and apathetic. They have disrupted sleep and bizarre eating and drinking habits. All of these symptoms are dramatically reversed when the child is removed to compassionate care in a hospital or foster home.

Psychosocial dwarfism

An adult GH-deficient dwarf has the body proportions of a young child. Radiographs (X-ray pictures) of growing ends of bone also show growth retardation in relation to the patient's chronological age. These changes are not apparent at birth but appear some time within the first two years of life. Puberty is often delayed, but untreated individuals may be fertile and give birth to normal children. When it appears in adults, GH deficiency produces only subtle changes, with minor decreases in strength and in the density of bones.

Growth hormone-deficient dwarfs respond dramatically to injections of human growth hormone. Supplies of GH were greatly limited in the past because the only source was GH extracted from human pituitary glands obtained at autopsies. With the availability of human GH manufactured by recombinant DNA technology using bacteria, the supply is potentially unlimited. Most treated patients achieve normal height, but in some, particularly those with the hereditary inability to synthesize growth hormone, antibodies to the injected growth hormone may block the therapeutic action. There is evidence that children with "constitutional short stature," that is, children from otherwise normal families in whom short stature is the rule in the absence of disease, may also respond to GH treatment.

Administration of human GH

Excess levels of growth hormone are most often caused by a benign tumour (adenoma) of somatotrophs of the pituitary gland. Rarely, a tumour of the lung or the pancreatic islets produces GHRH, which stimulates normal pituitary somatotrophs to excess secretion when released into the circulation. Even more rarely is there excessive, ectopic production of GH by tumour cells that do not ordinarily synthesize GH. If hypersecretion of growth hormone occurs during childhood, growth progresses at an inordinately rapid rate to extremes, 8 feet, 11 inches in the case of the "Alton Giant." Giantism is rare because such individuals usually have all of the infirmities described below for acromegaly.

The term acromegaly refers to the enlargement of the distal parts of the body; there is, in fact, progressive enlargement of the hands, feet, chin, and nose. Most other organs also become enlarged. The presence of a pituitary

tumour causes severe headaches, and the pressure of the tumour on the optic chiasm causes visual defects.

The acromegalic patient has overgrown supraorbital ridges, enlarged nasal sinuses that give a sonorous quality to the voice, an overgrown jaw, spaces between the teeth, and an enlarged tongue. The skin thickens, producing a permanently furrowed brow. The enlarged fingers are no longer tapered and become spatulated.

Because the metabolic actions of growth hormone are antagonistic to those of insulin, some acromegalic patients develop diabetes mellitus and are subject to all of its complications. Other problems include elevated blood pressure, heart disease, and progressive arthritis. Finally, because some of these tumours produce prolactin as well as growth hormone, males may have enlarged breasts, and both sexes may show abnormal lactation (milk secretion). Acromegaly can be treated with a considerable degree of success with surgery, with X-ray therapy, and with drugs such as bromocriptine or a synthetic, long-acting somatostatin.

The "parenting" hormone

Prolactin. On the evolutionary scale, prolactin is an ancient hormone serving multiple roles in mediating the care of progeny (it has been called the "parenting" hormone). Prolactin is a large protein molecule synthesized and secreted from cells, the lactotrophs, which compose 20 percent of the anterior pituitary gland and are located largely in the two lateral portions. Unlike other anterior pituitary cells whose activities are stimulated by hypothalamic-releasing hormones, the major modulating influence on lactotroph secretion is the inhibitory effect of the neurotransmitter dopamine, which, in the case of prolactin, functions as a hypothalamic neurohormone.

In the female, the major action of prolactin is to initiate and sustain lactation. In a breast-feeding mother, tactile stimulation of the nipples and breast by the suckling infant blocks the secretion of hypothalamic dopamine into the hypophyseal-portal circulation. This results in a sharp rise in serum prolactin levels followed by a prompt fall once feeding has stopped. Prolactin also inhibits secretion of GnRH from the hypothalamus and blocks the action of gonadotropins on the gonads. Thus, high prolactin levels reduce fertility in the female, protecting the lactating woman from a premature pregnancy. This protection is not absolute, however. Prolactin secretion is stimulated

Actions of estrogens

by estrogens and by TRH. This action of estrogens, much diminished in men, causes the level of prolactin to be relatively high in women. Finally, prolactin secretion is also stimulated by stress and exercise.

Prolactin deficiency occurs along with the loss of other pituitary hormones in patients with panhypopituitarism from any cause. A striking example is that of Sheehan's syndrome, in which the anterior pituitary gland of the pregnant woman, for reasons poorly understood, is partly or totally destroyed during or shortly after the woman gives birth. Characteristically, in such a woman, breast milk is never produced.

Abnormally increased prolactin secretion may have many causes, including any of the many disease processes that damage the pituitary stalk (interrupting the flow of the prolactin inhibitor dopamine from passing through the hypophyseal-portal circulation to reach the lactotroph) and a number of drugs (particularly those used for the treatment of mental disease, high blood pressure, and the relief of pain). The most frequent cause of abnormally high prolactin levels is a tumour of the lactotrophs, termed a prolactinoma. In a large minority of hyperprolactinemic patients, however, no cause is discernible, and they are said to have "idiopathic hyperprolactinemia."

Frequency of prolactinomas

Prolactinomas were once thought to be quite rare. With the advent, in 1971, of a sensitive test for measuring serum prolactin, however, it became evident that hyperprolactinemia was common and that prolactinoma was the most frequently occurring pituitary tumour. It can be found usually in young adult females with abnormal lactation (galactorrhea) and disappearance of menstruation (amenorrhea), loss of sexual desire, and an inability to conceive. Prolactinomas are five times less common in men but are usually larger because the symptoms, particularly impotence, are gradual in onset.

In both sexes, symptoms attributable to the tumour mass alone, that is, headache and visual field defects, also occur. In women estrogen levels are decreased, resulting in osteoporosis. In men testosterone levels are lowered, contributing to a loss of physical strength as well as to impotence.

Initially, patients with prolactinomas were treated with X-ray therapy or neurosurgery; however, these forms of therapy largely have been replaced by the administration of potent drugs that mimic the neurotransmitter action of dopamine. These drugs promptly reduce elevated prolactin levels in all hyperprolactinemic patients, regardless of cause. In addition, individuals with prolactinoma usually demonstrate, sometimes quite strikingly, a decrease in the size of the tumour. This more conservative, pharmacological approach to treatment has been strengthened by the finding that patients with small prolactinomas may do well and exhibit no further tumour growth or increases in serum prolactin levels when left untreated.

THE POSTERIOR PITUITARY (NEUROHYPOPHYSIS)

Neurohypophyseal unit. The posterior pituitary lobe consists largely of extensions of processes (axons) from large clusters of cell bodies called nuclei (Figure 11). One pair, known as the supraoptic nuclei, lies immediately above the optic tract, while the other pair, the paraventricular nuclei, lies on each side of the third ventricle of the brain. This anatomical complex forms the neurohypophyseal unit. There are neural connections upward to other centres of the brain, including a centre that modulates thirst. The two major neurohypophyseal hormones, vasopressin (also called antidiuretic hormone [ADH]) and oxytocin, synthesized in the cell body of the nuclei, descend through the long axons to be stored in secretory granules in the posterior lobe of the pituitary. Functionally, therefore, the posterior lobe is a storage and secretion site only.

Evolutionary origins

Oxytocin and vasopressin. Oxytocin and vasopressin evolved from a single, primordial neurohypophyseal hormone, vasotocin, which is still present in lower vertebrates.

After C.R. Kleeman in L.J. DeGroot *et al.* (eds.), *Endocrinology*, vol. 1, (1979); Grune and Stratton, Inc.

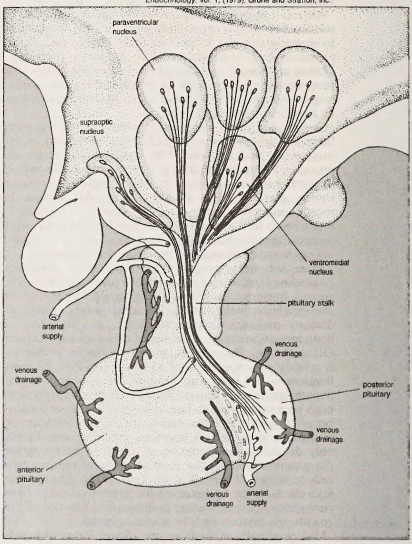


Figure 11: The neurohypophyseal unit.

Within the secretory granule, each hormone is attached to a large carrier protein, called neurophysin, from which it separates when the granule is discharged into the bloodstream. While vasopressin and oxytocin remain the major hormones synthesized by the neurohypophysis, it has become clear in recent years that other neuropeptides, including somatostatin, TRH, GnRH, CRF, and endogenous opiates are synthesized as well.

Vasopressin plays a key role in maintaining a constant total volume of water in the body and also in maintaining within narrow limits the concentration of dissolved substance (the osmolality) in those body fluids located outside body cells (extracellular water). In 1849, Claude Bernard noted that a small needle prick in the base of the brain led to a permanent, greatly increased urinary output. Following this, there ensued from the scientific community a confusing mixture of valid observations and false leads, until in the early 1930s Ernest Basil Verney showed unequivocally that the injection of a highly concentrated (hypertonic) salt solution into the carotid artery (the major artery carrying blood to the brain) resulted in a prompt increase in the excretion of urine from an animal's kidneys. This demonstrated (1) that there was a factor in the brain (vasopressin), which when let loose into the circulation enhanced water output, and (2) that this hormonal activity was stimulated by an increase in osmolality. It is now also known that vasopressin secretion increases in response to pain or stress.

Osmoreceptors

There is an osmoreceptor in the hypothalamus, which, when activated, leads to the release of vasopressin. Similarly, there exist two structures that are highly sensitive to distension and, in effect, serve as receptors for monitoring the total amount of fluid within the circulating blood: one is the carotid sinus, which is high in the neck and intimately associated with each carotid artery; and the other is a grouping of specialized cells in the left atrium of the heart. When the tissues of these structures are stretched by an expanding blood volume, nerves from these receptors carry impulses to the hypothalamus, thus inhibiting the cells of the neurohypophysis, shutting off the secretion of vasopressin, and resulting in increased urinary excretion of water.

The role of oxytocin is important, but more limited in scope. Oxytocin stimulates the contractions of the uterus, which are ongoing during the birth process; injections of oxytocin are used by obstetricians to stimulate uterine contractions in women whose labour is flagging. Oxytocin also prompts the milk glands of the mother's breast to release milk (milk let-down) within seconds after an infant begins to suckle by stimulating the contraction of muscular elements in the vicinity of the milk-containing glands.

There are no known diseases due to under- or overproduction of oxytocin. Emotional influences can affect oxytocin secretion; milk let-down may be premature, stimulated only by the cry of a hungry baby. While oxytocin is used to stimulate labour, delivery still may be normal in women in whom oxytocin deficiency is present.

Diabetes insipidus and inappropriate secretion of vasopressin. The clinical manifestations of diseases of the posterior pituitary may be considered in the context of two extremes in body water content: water intoxication (overhydration) and dehydration.

Water intoxication occurs when the body's ability to dispose of fluid is overcome by a large fluid intake or when the plasma volume percentage of water is increased because of defective mechanisms for the disposal of excess fluid, as is the case when more vasopressin is secreted than the body needs. Water intoxication from excessive fluid intake occurs rarely, having been reported in psychotic individuals, the winners of water-drinking contests, and individuals who have indulged in the overconsumption of beer (beer potomania).

A person becomes dehydrated when deprived of fluids or when there is excessive fluid loss from the body, such as occurs from excessive sweating, vomiting, or diarrhea. In these circumstances, the volume of fluid in the plasma is reduced and the concentration of solutes (the osmolality) is therefore proportionately increased. The decrease in body fluid and the proportional increase in solutes serve as potent stimuli for the secretion of vasopressin, which then acts on the kidneys to minimize urinary losses of water.

There are three disease states in which this regulatory mechanism fails. The first is termed adipsia (or hypodipsia), a rare disorder in which the brain's thirst centre is damaged. Individuals afflicted with adipsia become dehydrated, with little or no feeling of thirst. The problem can be alleviated by instructing them to drink adequate quantities of fluids at measured intervals.

Diabetes insipidus

The second disease, and by far the most common, is diabetes insipidus, so named because of the large volume of urine (which is tasteless rather than sweet as is the case in diabetes mellitus, where large quantities of the sugar glucose are present in the urine). Diabetes insipidus may be caused by trauma, including brain surgery, damage from brain tumours, or granulomatous infiltration, as in sarcoidosis, or, occasionally, for no discernible reason. Diabetes insipidus is rarely hereditary. Despite the frequency of head trauma, diabetes insipidus is an uncommon complication largely because it does not manifest itself until more than 85 percent of the neurohypophysis is destroyed.

The symptoms of diabetes insipidus include large urine volumes (usually from two to six litres each day, although up to 18 litres per day has been recorded) associated with frequent thirst and the ingestion of large quantities of water. If fluids are freely available the patient remains well except for the inconvenience of frequent drinking and of insomnia due to frequent urination. Occasionally, as a result of a patient's ongoing reluctance to urinate at frequent intervals, dilation of the kidney pelvis (hydronephrosis) and ureters (hydroureter) will occur, subsequently damaging kidney function. In the absence of a source of fluid, the patient becomes irritable and stuporous and will ultimately lapse into a coma and die. A highly satisfactory treatment is a long-acting, chemically modified form of vasopressin called desmopressin.

Nephrogenic diabetes insipidus

The third deficiency disease, a variant of diabetes insipidus, is called nephrogenic diabetes insipidus. It is a hereditary disorder linked to the X chromosome; males exhibit the disease whereas females are affected only slightly but are the sole carriers. The cause of the illness is not a deficiency of vasopressin (serum vasopressin levels may even be elevated); rather, the kidney tubules are defective and do not respond properly to the presence of vasopressin. Treatment with vasopressin or desmopressin is ineffective, but patients respond well to adequate fluid intake and a reduction in salt consumption.

The syndrome of inappropriate antidiuretic hormone secretion (SIADH) may be acute and life-threatening, characterized by sleepiness that progresses to convulsions, coma, and death, or, more commonly, chronic, in which the onset is far slower and is associated with few or even no symptoms.

Tumours of the neurohypophysis that secrete excess amounts of vasopressin have not been observed; however, other tumours, particularly those of the lung, may secrete large amounts of vasopressin, producing SIADH. For reasons not understood, any tumour that occurs in the brain may be associated with SIADH, and the syndrome has been noted in patients who have a wide variety of lung diseases. Finally, certain drugs, particularly chlorpropamide (used in the treatment of diabetes mellitus), that augment the action of normal amounts of secreted vasopressin may produce symptoms of SIADH.

The syndrome involves a lower than normal concentration of salt in the circulating fluid. Treatment of the acute form of SIADH involves the administration of concentrated salt solutions along with a powerful diuretic, so that the concentration of solutes is increased while the total plasma volume is decreased. The chronic form is satisfactorily treated with a drug called demeclocycline.

THE THYROID GLAND

All animal life requires oxygen for sustenance, and the human species is no exception. Oxygen drives the basic metabolic processes that permit growth, development, reproduction, physical movement, and constant body temperature. The complex of chemical interactions necessary to sustain these processes is called metabolism, and the

prime, overall regulators of metabolism are the thyroid hormones.

Anatomy. The thyroid gland is located in the anterior part of the neck in the midline. It consists of two lateral lobes lying on each side of the thyroid cartilage (Adam's apple) and connected by a band of tissue called the isthmus. It is one of the larger endocrine glands, and its capacity to grow is phenomenal. Any enlargement of the thyroid, regardless of cause, is called a goitre. The thyroid arises in the embryo from a downward outpouching of the floor of the fetal pharynx, and a persisting remnant of this migration is known as a thyroglossal duct.

Goitre

If viewed under a three-dimensional microscope, the resting thyroid is seen as a collection of small, generally globular sacs, called follicles, filled with the prohormone thyroglobulin. The cells lining these globules are called follicular cells, and it is their function to synthesize thyroid hormones as part of the prohormone thyroglobulin and either to secrete them directly into the circulation or store them within the follicles. When the individual's requirement for thyroid hormone increases, thyroglobulin is split into its component parts, and the thyroid hormone thus released passes through the follicular cells to enter the circulation. Nestled in the spaces between the follicles are parafollicular cells. These, in essence, form a separate endocrine organ. They have an entirely distinct embryological origin, and they are not embedded in the substance of the thyroid gland, in many species other than man (see below *The parathyroid glands: Calcitonin*).

Biochemistry. The thyroid hormones are not proteins; rather, they are modifications, called thyronines, of an amino acid, tyrosine. Thyroid hormones are heavily laden with iodine. The major active thyroid hormones are thyroxine (T_4) and triiodothyronine (T_3). Even though the thyroid gland manufactures considerably more T_4 than T_3, T_3 is roughly 2½ times more potent than T_4. Indeed, in many ways, T_4 serves as an additional, circulating depot for T_3 in that when T_4 leaves the circulation and travels through the cytoplasm to the nucleus of the target cell, its action at that site is preceded or accompanied by its conversion to T_3.

Thyroid hormones

Most of the T_4 and T_3 secreted by the thyroid is bound to special proteins (thyroxine-binding globulin [TBG] and prealbumins) in the serum, although small amounts of these hormones travel freely in the serum and are readily taken up by tissues to be replenished instantaneously from the T_4 that had been attached to the binding proteins.

Essentially all the cells in the body are target cells of thyroid hormones. The major function of the thyroid hormones is to stimulate the synthesis of protein once they have entered the cell nucleus. Another important function is to stimulate the activity of the cell's mitochondria. These intracellular organelles are the sites at which there is a controlled exchange of energy. Some energy is conserved for the body's functionings, while the remainder is dissipated as heat. The proportion of energy devoted to each of these processes is controlled by the thyroid hormones. There are other intracellular thyroid hormone functions that are not well understood, but it is clear that thyroid hormones modulate protein, carbohydrate, fat, and vitamin metabolism, as well as the generation of body heat. Thyroid hormones also modify the activity of the autonomic nervous system.

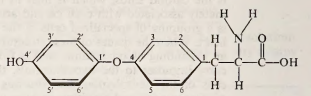
Regulation of hormone secretion. While multiple factors, including nerves supplying the thyroid gland, influence thyroid hormone secretion, by far the major influences are the negative feedback loops. The thyroid is a prime example of the negative feedback effects of the hypothalamic-pituitary-target organ axis. Briefly, thyroid hormones inhibit the release of thyrotropin-releasing hormone (TRH) from the hypothalamus and thyrotropin (thyroid-stimulating hormone [TSH]) from the anterior pituitary. Increased consumption of thyroid hormones decreases their concentration in the circulating fluids, resulting in enhanced thyrotropin secretion and thus an increased thyroid hormone secretion until a normal serum level is regained. Conversely, with the administration of the thyroid hormones, the resultant increased serum levels inhibit TRH and thyrotropin secretion and reduce the secretion of thyroid hormone from the thyroid gland until the elevated circulating thyroid level is returned to normal. If an amount of thyroid hormone equal to the normal daily thyroid output is administered to a patient, the thyroid gland is effectively suppressed; it produces no thyroid hormone because levels of circulating TSH are greatly reduced.

Major regulatory influences

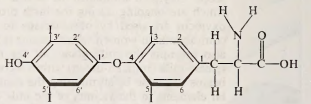
There is an important extrathyroidal mechanism for modulating thyroid hormonal activity, that is, the controlled conversion of T_4 into either the potent hormone T_3 or the inactive molecule rT_3 (Figure 12). Tissue enzymes, particularly abundant in the liver and kidney, control the conversion of T_4 to T_3 or reverse triiodothyronine (rT_3). Consequently, when T_4 is metabolized to T_3, thyroid hormone action is enhanced. Similarly, when the pathway for the conversion of T_4 to rT_3 is favoured, T_3 levels fall and thyroid hormone activity in that particular tissue is proportionally decreased.

Aside from the regulatory functions, other factors, external or internal, may also influence the circulating levels and utilization of thyroid hormones. In all forms of malnutrition, including anorexia nervosa, there is a significant reduction in the conversion of T_4 into T_3. The commensurate decrease in oxygen consumption and metabolic rate has survival value for a person deprived of adequate food to sustain health; in effect, death from starvation is postponed. Iodine intake is important because an inadequate dietary supply leads to reduced circulating thyroid levels and an ensuing increase in serum thyrotropin levels. This increase, while perhaps not adequate to produce sufficient thyroid hormone, nevertheless stimulates growth of the thyroid, with the resultant appearance of a goitre. In the short term, low environmental temperature leads to in-

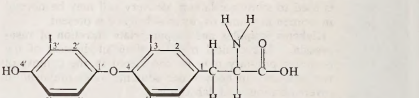
External and internal influences



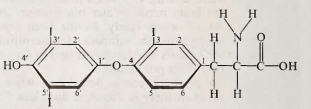
thyronine



3,5,3′,5′-tetraiodothyronine (T_4)
(thyroxine)



3,5,3′-triiodothyronine (T_3)



3,3′,5′-triiodothyronine
(reverse T_3; rT_3)

Figure 12: Structural diagrams of T_3, rT_3, and T_4, showing the synthesis of T_3 and rT_3 from T_4.

creased utilization of thyroid hormones, activation of the hypothalamic-pituitary-thyroid axis, and a consequent rise in T_4 and T_3 levels. As the environmental temperature rises, the converse results, and small, appropriate changes in normal persons have been noted with changes of season.

Finally, thyroid hormone levels may be affected by many illnesses that have nothing directly to do with the thyroid gland. For this reason, it is not easy to ascertain with certainty the influence of aging on thyroid hormone activity because it is difficult to accumulate large numbers of aged subjects who can be said to be free of any disease. It is generally agreed, however, that few important changes occur in thyroid activity during the normal aging process.

Diseases and disorders. *Hyperthyroidism.* When the human body is exposed to excessive amounts of thyroid hormone the result is a disease known as hyperthyroidism (or thyrotoxicosis). The most common cause of hyperthyroidism is Graves' disease, named after the Irish physician Robert J. Graves, who was among the first to describe it. It is noteworthy that hyperthyroidism is at least seven times more common in women than in men, although the reasons for this are poorly understood. Because there is a complex, hereditary tendency for the production of thyroid autoantibodies, it is not rare for Graves' disease to occur in many family members.

Graves' disease

Hyperthyroidism typically begins with a gradual onset of a constellation of symptoms, including increased nervousness and emotional instability associated with a fine tremor of the hands. The patient feels warm, perspires freely, and is intolerant of heat since a greater proportion of the body's energy is dissipated as heat. The pulse races, the heart thumps, and the systolic element of the blood pressure is elevated. In severe cases of hyperthyroidism, heart failure may occur. The drive to physical overactivity is dampened by increasing weakness and easy fatigue. Bowel movements may be normal, but they are often punctuated by bouts of diarrhea. Menstrual periods may become scant or may disappear entirely. Perhaps most striking is the apparent paradox of an increase in appetite associated with a loss of weight, the result of the fact that the excess of thyroid hormones leads to an increased metabolism. There is often, but not always, a swelling in the neck, and the physician's fingers may often detect the outline of an enlarged thyroid gland.

In patients with Graves' disease, an additional group of symptoms may appear. The eyes protrude (exophthalmos) and the distance between the opened eyelids increases so that in extreme cases the eyes may not close completely. The eyeball muscles and the entire orbit becomes inflamed and the patient may complain of double vision. Less often, there is a thickening of the skin over the shins (localized myxedema) and of the skin of the fingers (clubbing).

These changes, along with hyperthyroidism itself, stem from a pathological process called autoimmunity in which the body's immune system generates autoantibodies, called immunoglobulins, that are harmful to the body's own tissues. The first and most common cause of hyperthyroidism is the presence of antibodies producing Graves' disease. At least three sets of antibodies are involved. In the genesis of thyroid hypofunction, there is a fourth set of antibodies that competes with the hormones but does not induce the actions of the stimulating hormones once they are bound to the receptors.

The first set of antibodies is called the thyroid-stimulating immunoglobulins (TSI), which exert extraordinary effects unique throughout the endocrine system. They have a molecular configuration that mimics that of thyrotropin so that they are attracted to, and bind tightly with, the same receptors on the surface of thyroid cells that attract thyrotropin. The effects of thyrotropin are mimicked exactly. The result of TSI stimulation is the same as that of thyrotropin stimulation: thus, the number of follicular cells multiply and the thyroid enlarges, the follicles empty as the prohormone thyroglobulin is split, thyroid hormones are released, and the follicular cells are stimulated to synthesize and secrete excessive amounts of thyroid hormone. The end result is hyperthyroidism, or thyrotoxicosis.

TSI stimulation

The second set of autoantibodies attack orbital contents, including the eyeball muscles, producing Graves' ophthalmopathy and, less frequently, localized myxedema (dry, waxy swelling of the skin). The third set of antibodies is cytotoxic; that is, they damage and eventually destroy follicular cells. These cytotoxic immunoglobulins are an important cause of hypothyroidism, but when present early in the course of Graves' disease, they may only limit the effect of TSI. Thus a patient may manifest ophthalmopathy with normal or even reduced thyroid function. Furthermore, cytotoxic antibodies, even in the absence of TSI, may acutely damage thyroid follicles, leading to a leakage of large quantities of thyroid hormones so that a thyrotoxic state ensues.

The second most common cause of hyperthyroidism is toxic multinodular goitre. It begins early in life with iodine deficiency or other factors that block thyroid hormone secretion; the resulting low T_4 and T_3 levels lead to unremitting TSH secretion and to constant thyroid gland stimulation. This, in turn, produces glandular enlargements and the eventual formation of multiple nodules that produce excessive amounts of thyroid hormones autonomously. Less common is a benign tumour (toxic adenoma) of the thyroid, and rarely a malignant tumour may hypersecrete thyroid hormones. In such patients, hyperthyroidism may be due to overproduction of hormones from a metastatic deposit located in one or more parts of the skeleton, even though the thyroid gland itself has been removed surgically. Another rare form of hyperthyroidism results from inappropriate thyrotropin secretion. This may be caused by increased thyrotropin secretion resulting from a tumour of the pituitary thyrotrophs. Another cause of thyrotropin overproduction and secretion is the loss of cell receptors for thyroid hormones on the surface of thyrotrophs. As a consequence of this loss, the pituitary is not inhibited from releasing thyrotropin, resulting in persisting thyrotropin release.

Hyperthyroidism may also result from a hyperfunctioning ectopic tumour of thyroid tissue in the ovary (struma ovarii) or from the ingestion of excessive amounts of thyroid hormones. On occasion a person will, in order to lose weight or for some other reason, take large, toxic unprescribed amounts of thyroid hormone and may persist even to the point where surgical removal of the thyroid gland becomes necessary.

Effective treatments for hyperthyroidism include (1) surgical removal of all but a remnant of the thyroid gland, (2) the administration of drugs that specifically block the synthesis and release of thyroid hormones, and (3) the administration of radioactive iodine. This last form of treatment is effective because the thyroid gland, unable to distinguish between stable and radioactive forms of iodine, extracts both from the serum. Thus, follicular cells are damaged by the concentration of radioactivity within them to the point that the hyperthyroid state is relieved and the thyroid function returns to normal. In some instances, as is the case in excessive hormone release from inflammation of the thyroid or following ingestion of large amounts of thyroid hormone, drugs that block the manifestations of thyroid action on tissues, such as propranolol, are effective. Finally, for reasons not fully understood, using stable (nonradioactive) iodine also impairs release of thyroxine from the gland: improvement, however, may be short lived.

Treatments for hyperthyroidism

Hypothyroidism. Like hyperthyroidism, hypothyroidism can have many causes. It is, however, less common. In fact, overtreatment of hyperthyroidism with either radioiodine or surgery has emerged as the most frequent cause of hypothyroidism. In other instances, however, a child is born without a thyroid or an adult becomes hypothyroid without apparent cause. In some cases, autoantibodies appear and bind to thyrotropin receptors on the follicular cell, but unlike TSI, these autoantibodies are not agonists and do not accelerate the secretion of thyroid hormones. Instead, they are antagonists because they block access of thyrotropin to the receptor. As a result of their actions, the thyroid gland atrophies. Hypothyroidism may also occur as a result of disease of the cells of the hypothalamus that produce TRH or of the thyrotrophs of the anterior pituitary.

Hypothyroidism may also be associated with an enlarged

Hashimoto's thyroiditis

thyroid, a goitre. This is most commonly caused by inflammation of the thyroid (Hashimoto's thyroiditis) due to cytotoxic autoantibodies (see above *Thyroid gland: Hyperthyroidism*). The thyroid enlarges because of a heavy infiltration of white blood cells called lymphocytes. As discussed above, iodine deficiency results in goitre formation because of constant stimulation from elevated TSH levels in the serum. When iodine deficiency is severe, these compensatory efforts are inadequate and the patient becomes hypothyroid. In rare families there appears a hereditary absence of one of the enzymes essential for the synthesis of thyroid hormones. Although such individuals are hypothyroid from birth, they develop large goitres because of constant stimulation of the thyroid by TSH, a condition referred to as goitrous cretinism.

A number of drugs can block thyroid hormone synthesis and thus lead to goitrous hypothyroidism. Among them are the antithyroid drugs used in the treatment of hyperthyroidism, and lithium, prescribed for psychiatric disorders. There are a number of naturally occurring vegetable goitrogens, particularly cabbage. Finally hypothyroidism may be due to the absence of tissue receptors for the thyroid hormones. Persons with this very rare disorder have high but ineffectual serum levels of T_4 and T_3.

The onset of hypothyroidism may be gradual and subtle, so that it is often missed not only by the patient but also by a physician. It may be mild and difficult to diagnose, or all of its symptoms and conditions, called myxedema, may be present. The term myxedema stems from the fact that, for reasons not well understood, the hypothyroid patient produces an excess of a thick protein-containing (myxomatous) fluid that is deposited in the skin and other organs.

In many instances, the hypothyroid patient shows symptoms diametrically opposed to those of the patient with thyrotoxicosis. The patient is sluggish in movement and thought and has a thick, dry skin with coarse, dry, thinning hair. The patient does not eat excessively but gains weight. (Excessively obese persons, however, are rarely hypothyroid.) The tongue is large and impedes articulation of the guttural voice. The eyes are puffy and the lids lowered. Reflexes are slow, and there is continuing weakness. Females often have excessive menstrual bleeding and are relatively infertile. Patients prefer hot weather and are intolerant of cold. In fact, those with myxedema cannot generate additional body heat in response to a cold environment, so that when exposed to extreme cold, their body temperature may fall to levels as low as 74° F (23.3° C).

Myxedema is relatively common in the elderly, and the symptoms and signs are often mistaken for changes attributable to old age. While it is true that every endocrinologic disorder, whether hyperfunction or hypofunction, has been found to be sometimes associated with a mental aberration, most often depression, this may be striking in severe hypothyroidism; it has been called "myxedema madness." Treatment with T_4 may return the patient to a normal mental state, but the mental illness may remain unchanged or in some instances become even worse.

The same myxomatous fluid that infiltrates the skin often accumulates in body cavities as well. Thus what appears to be an enlarged heart in a chest X-ray film may be a benign collection of fluid in the pericardium, and similar changes may be found in the pleural and abdominal cavities.

Cretinism

Since the thyroid hormones pass only poorly from the maternal to the fetal circulation, iodine-deficient fetuses or those without thyroid glands become hypothyroid in utero and are born as cretins (infants whose growth and mental development are arrested) with a characteristic appearance somewhat similar to that present in myxedematous adults. Hypothyroidism also may be produced in the fetus when a pregnant woman is exposed to radioactive iodine or antithyroid drugs. Cretinism is associated with severe mental retardation, so that it is essential that hypothyroid infants be treated promptly with thyroid hormone. Indeed, it has become routine to check thyrotropin and T_4 levels in all infants at birth so that a child with any degree of hypothyroidism can be identified and promptly given the appropriate treatment.

Treatment of the adult with myxedema is relatively simple. The patient is given enough thyroxine to increase serum T_4 and decrease serum thyrotropin to normal levels. While the mental retardation of infantile cretinism cannot be reversed, both children and adults can be returned to a state of normal physical health.

Thyroid tumours. Thyroid tumours are remarkable in two respects. First, patients exposed to radiation from any source (nuclear blast, radioactive iodine, or X rays) have a much increased risk of developing thyroid tumours, including thyroid cancers. Second, unlike many other organ cancers, the most common thyroid tumour, a papillary carcinoma, pursues a slowly developing, painless course compatible with a long life span, and it is held in check when enough thyroxin is administered to suppress thyrotropin secretion. Other, less common thyroid tumours pursue a much more threatening course, and the most malignant of these may cause death within a few months to a few years.

Diagnostic techniques have improved to the point that it is relatively easy to ascertain the nature of a lump (mass) found on the thyroid gland. An image of the accumulation of administered radioactive iodine or technetium in the thyroid (thyroid scan) will demonstrate whether the mass is "hot" or "cold," that is, whether the mass is functionally active or not, functional activity being rare in thyroid cancers. Similarly, imaging with ultrasound will reveal whether the mass is fluid (cystic) or solid, cancers being solid. Finally, cells obtained by suction through a fine needle inserted through the skin into the mass may be examined under the microscope. These methods, particularly the last, may obviate the need for exploratory thyroid surgery.

The treatment of thyroid masses, also known as thyroid nodules, has long been controversial, but with increasing awareness of the slow course that many of these tumours pursue, surgeons now employ less radical procedures in dealing with them.

THE PARATHYROID GLANDS

Importance of calcium

The level of calcium in the blood is closely regulated, and wide fluctuations in either direction can be life-threatening. Calcium is a key element in the human body. Not only does it serve as the major constituent for bone, but it is also essential for the normal functioning of all body cells, as it is a mediator for many cell functions. For example, without calcium, blood will not clot. Many of these actions also require adequate supplies of magnesium and phosphorus. A healthy body needs a regular, continuous supply of these elements: about a gram each day for calcium and phosphorus and about one-third as much for magnesium.

Almost all the calcium contained in the body is deposited in bone (about 1.3 kilograms in the normal adult). While this mass provides skeletal support and serves as a reserve from which calcium may be mobilized, it is the remaining 1 percent, dissolved in body fluids, whose concentration is so carefully monitored. In the plasma, calcium exists largely as a dissociated ion (Ca^{2+}) loosely bound to plasma proteins with a small proportion bound more tightly to phosphate and citrate. To insure that calcium levels and distribution are maintained within narrow limits, parathyroid hormone (PTH), calcitonin, and the calciferols (the active metabolites of vitamin D) serve regulatory functions.

Anatomy. The parathyroid glands, usually four in number, are small structures adhering to or even imbedded in the substance of the thyroid gland. It is not surprising, therefore, that they were recognized as distinct endocrine organs rather late in the history of endocrinology, first described by a Swedish anatomist, Ivar Sandström, in 1880. At the beginning of the 20th century, symptoms due to parathyroid deficiency were attributed to the absence of the thyroid since the surgical removal of one was frequently accompanied by the inadvertent removal of the others. In 1909 an American pathologist, William G. MacCallum, recognized that parathyroid deficiency could be mitigated by the injection of calcium salts, and not until 1925 was an active parathyroid extract prepared by a Canadian biochemist, James B. Collip. In 1925 an Austrian surgeon, Felix Mandl, was the first to remove a

parathyroid tumour from a patient, and thereafter this and related subjects were extensively explored by the American clinical endocrinologist Fuller Albright.

Embryological development

The parathyroids arise in the embryo from the third and fourth pairs of branchial pouches, bilateral grooves resembling gill slits in the neck of the embryo and reminders of man's evolutionary debt to fishes.

Hormones. *Parathyroid hormone.* The parathyroids produce only one major hormone, parathyroid hormone (PTH), also called parathormone. Under the microscope the PTH-producing cells, the chief cells, occur in sheets interspersed with areas of fatty tissue. Occasionally the cells are arranged in follicles, similar to but smaller than those present in the thyroid gland. In common with other endocrine glands, the parathyroids synthesize a large prohormone, which is inactive. At the time of secretion the prohormone is split into an inactive fragment and PTH (a polypeptide containing 84 amino acids).

In contrast to the elaborate mechanisms controlling the secretion of other endocrine glands, the major determinant of PTH secretion is the level of ionized calcium in the serum (see above *The nature of endocrine regulation*). Should the serum calcium level rise, PTH secretion is inhibited. Conversely, should it fall, PTH levels rise. Magnesium controls PTH secretion in a similar fashion.

Actions of parathormone

The actions of PTH are multiple but they are all geared toward raising the level of ionized calcium in the plasma. Parathormone mobilizes calcium from bone by stimulating the activity of large, bone-dissolving cells called osteoclasts. It acts on the kidney to enhance the reabsorption of calcium by kidney tubules so that excretion of calcium in the urine is reduced. Parathyroid hormone acting in concert with vitamin D metabolites also enhances the absorption of ingested calcium from the bowel, and there is evidence that it provokes the transfer of some calcium from the milk in the breast of a lactating woman into her blood. On the other hand, PTH is a powerful inhibitor of renal tubular reabsorption of phosphate. Finally, an ancillary action of PTH is to assist in the regulation of body acidity by blocking tubular reabsorption of bicarbonate.

Calcitonin. Calcitonin was not recognized as a specific hormone until 1962. Calcitonin is a polypeptide containing 32 amino acids. It is synthesized and secreted from cells, termed parafollicular, or C, cells, which lie between the follicles of the thyroid gland. These cells do not have the same embryological origin as do the thyroid follicular cells; they migrate into the substance of the thyroid from a fetal structure called a branchial pouch. Human calcitonin differs considerably from the calcitonin of other species, and physicians take advantage of these differences when they administer salmon calcitonin, which provides a longer lasting, more potent action than does human calcitonin.

Major action

The major action of calcitonin is to lower the level of calcium in the blood by sharply inhibiting the ongoing dissolution of calcium from bone. Not unexpectedly, calcitonin secretion is stimulated whenever serum calcium levels rise above the normal range so that, between them, calcitonin and PTH effectively maintain steady calcemia in a normal individual.

Vitamin D and the calciferols. Unlike calcitonin, the awareness of vitamin D is relatively ancient. Vitamin D deficiency was first described more than 300 years ago as rickets, but it was not until 1971 that the chemical transformations that make vitamin D biologically active were described. The term vitamin D refers to a family of compounds that are derived from cholesterol. There are two major forms of vitamin D: vitamin D_3, found in animal tissues and often referred to as cholecalciferol, and vitamin D_2, found in plants and now better known as ergocalciferol. Both of these compounds are inactive precursors of potent metabolites; they fall, therefore, into the category of prohormones. This is true not only for the cholecalciferol found in animal tissues but also for that which is generated in human skin following exposure to ultraviolet light. These precursors are modified during their passage through the liver to a sterol called 25-hydroxycholecalciferol, and then further modifications, modulated by the serum PTH level, occur in the kidney. One of these products, 1,25-dihydroxycholecalciferol (calcitriol), is the most potent derivative of vitamin D. The other, 24,25-dihydroxycholecalciferol, has actions that are not clearly defined at present.

Vitamin D deficiency

Persons with a vitamin D deficiency suffer from rickets, characterized by soft, poorly calcified bone, along with poor absorption of calcium. Calcitriol or any of its precursors promotes a dramatic increase in the absorption of calcium by the intestine and a prompt repair of the diseased bone. It is generally agreed that the improvement in the bone results from the alleviation of the calcium deficiency; calcium is resorbed, but bone synthesis is not enhanced.

Diseases and disorders. *Hyperparathyroidism.* Overactivity of the parathyroid glands was originally thought to be a rare disorder because it was generally considered only in those patients who had definite symptoms. This view changed precipitously when the measurement of multiple plasma constituents, including calcium, became an integral part of a routine health examination. Hypercalcemia (excessive levels of calcium in the bloodstream) associated with few or no symptoms occurs in one in 1,000 adults, representing a large subpopulation in Western countries.

While there are many other disorders associated with elevated levels of calcium in the serum, including malignancy and the ingestion of too much vitamin D, primary hyperparathyroidism (primary in the sense that the parathyroid hyperfunction is not due to a known cause) is the preeminent cause of hypercalcemia. In hyperparathyroid patients, the hypercalcemia is often accompanied by a reduction in serum phosphorus levels and an increase in the levels of serum uric acid and serum acidity.

Almost all the symptoms of hyperparathyroidism result from hypercalcemia, but not all hypercalcemic patients become ill. (Thus, it is important for the physician to distinguish hyperparathyroidism from a chemical anomaly, called familial hypocalciuric hypercalcemia, in which elevated serum calcium levels are associated with a reduction in urinary calcium excretion. This condition is benign and usually no treatment is required.) Primary hyperparathyroidism results most often from an adenoma (a benign tumour), which secretes an excessive amount of PTH despite the elevation in serum calcium that it produces; because the adenoma is autonomous and not subject to negative feedback loops, elevated serum calcium levels are not followed by inhibition of PTH secretion. Primary hyperparathyroidism occasionally is associated with parathyroid hyperplasia, an increased number of hyperfunctioning cells that do not, however, cluster to form a typical adenoma. Rarely, a malignant tumour (a carcinoma of the parathyroid gland) may produce extraordinarily large amounts of PTH, which, in turn, produce dangerously high levels of serum calcium.

With the advent of screening tests, large numbers of persons with mildly elevated serum calcium levels have been identified although the majority of these individuals are without symptoms. This form of asymptomatic hypercalcemia occurs most frequently in postmenopausal women. Symptoms include weakness, loss of appetite and weight loss, nausea, vomiting, and mental depression. There may be increased urinary output with an increased thirst and fluid intake. Constipation is a frequent problem. With severe, rapidly progressing hyperparathyroidism, there may be bone pain, stupor, and even coma. Weakened bones may form cysts (osteitis fibrosa cystica) and may break after little or no physical stress (pathological fractures). Since calcium does not dissolve readily in serum, elevated levels result in a precipitation of calcium deposits in susceptible tissues, most prominently the kidney, and the pain of kidney stones (renal colic) is often the first evidence of hyperparathyroidism. Kidney damage may progress to the point where the patient's life is threatened.

Asymptomatic hypercalcemia

Although primary hyperparathyroidism may be hereditary or in some instances associated with multiple endocrine neoplasia (see below *Ectopic hormone and polyglandular disorders*), most often the cause of primary hyperparathyroidism is unknown. Known causes, referred to as secondary hyperparathyroidism, usually involve an unrelated kidney disease. When kidney failure occurs, serum calcium levels fall. The resulting increase in PTH

secretion often leads to severe bone disease along with intractable itching.

Causes of hypercalcemia

Hypercalcemia may result when malignant tumours (particularly of the lung) secrete substances, in most instances not PTH, that increase the rate of dissolution of bone. Another important cause of hypercalcemia is vitamin D intoxication (discussed below). The most common cause of hypercalcemia other than primary hyperparathyroidism results from invasion and destruction of bone by the spread of a cancer, most commonly cancer of the female breast. A number of drugs, most prominently diuretics such as hydrochlorothiazide or furosemide, may also increase serum calcium levels.

The treatment of symptomatic hyperparathyroidism is surgical removal of the tumour. The treatment of asymptomatic hyperparathyroidism is less clear-cut. Because some patients may remain symptom-free for years, one alternative is simply to observe the patient's course without treatment unless symptoms appear. If continued observation alone is psychologically distressing, however, surgical removal of the tumour is warranted. In the case of mild postmenopausal hyperparathyroidism, treatment with the estrogen hormone estradiol is effective for many patients.

If the serum calcium rises to dangerous levels, it can be lowered quickly by using intravenous fluids with a powerful diuretic, thus "washing out" the excess calcium. The drug plicamycin (mithramycin) is highly effective in lowering serum calcium, although it may have toxic side effects.

Hypoparathyroidism. If PTH secretion is greatly reduced or ceases entirely, mobilization of calcium from bone and other sources ceases, and a fall in serum calcium to abnormally low levels results. Hypoparathyroidism is a rare disorder; indeed, the most common cause is iatrogenic—*i.e.,* physician- or treatment-induced, such as the PTH deficiency that occurs following the inadvertent removal of parathyroid glands during thyroid surgery. Spontaneously occurring hypoparathyroidism is probably an autoimmune disease because serum autoantibodies are found in some afflicted individuals. This form of hypoparathyroidism may appear in the syndrome of multiple endocrine deficiencies (see below *Ectopic hormone and polyglandular disorders*). Impaired PTH secretion may occasionally occur in the presence of intact parathyroid glands. Such is the case when a person suffers from magnesium deficiency, usually associated with alcoholism. In such patients serum calcium levels remain persistently low until the magnesium deficiency is repaired. Finally, Albright described what he termed pseudohypoparathyroidism in which there is a defect in the binding of PTH to its cell surface receptor.

Symptoms of hypoparathyroidism

The symptoms of hypoparathyroidism are essentially those resulting from low levels of serum calcium. Most prominent is muscular cramping and twitching, exemplified dramatically by carpopedal (wrist and foot) spasms; during the spasms there are painful cramps of the toes and feet, along with severe, tetanic contractions of the muscles of the hands so that the four fingers are rigidly extended while the thumb presses against the palm. This neuromuscular excitability can progress to generalized convulsions. In addition, patients with long-standing hypocalcemia develop cataracts and calcification in the basal ganglia of the brain, which in turn can produce symptoms of parkinsonism. Occasionally, patients also have a spotty depigmentation of the skin (vitiligo) and hair loss. Patients suffering from pseudohypoparathyroidism also may have peculiar skeletal abnormalities: "short coupled," with a short neck and extremities, obese, with a rounded face, and sometimes shortened metacarpal bones.

When treatment is urgent, the patient is given calcium salts intravenously. Long-term therapy consists of treatment with vitamin D or one of its metabolites, along with calcium salts by mouth. Serum calcium levels must be monitored to be certain that, on the one hand, the patient is given enough medication to avoid hypocalcemia and, on the other hand, to prevent the hazards of hypercalcemia with its attendant complications, such as kidney stones.

It should be noted that there are causes for hypocalcemia other than hypoparathyroidism. In the past, vitamin D deficiency (rickets) was a common cause, but with the wide distribution of vitamin D supplements in milk and other foods this has become a rare event. There remain, however, patients who suffer from abnormalities in the metabolism of vitamin D (vitamin D-resistant rickets), which may be treated effectively either with very large doses of vitamin D or with 1,25-dihydroxycholecalciferol. Severe inflammation of the pancreas (pancreatitis) is associated with hypocalcemia, and low serum calcium levels may also occur in patients who suffer from intestinal malabsorption (sprue). In these individuals, ingested calcium binds to unabsorbed fat and is excreted. Treatment of the underlying condition relieves the symptoms.

Hypercalcitoninemia. It was not until 1968 that tumours of the parafollicular cells of the thyroid gland were discovered to secrete large amounts of calcitonin. These tumours sometimes occur among family members and sometimes as isolated cases. Such tumours, known as medullary carcinomas of the thyroid, also occur in one of the forms of multiple endocrine neoplasia (see below *Ectopic hormone and polyglandular disorders*). In most patients, serum calcium levels are not low, as might be expected, because any tendency to hypocalcemia is countered by increased PTH secretion. The threat of medullary carcinoma is the fact that it invades local areas in the neck and spreads to distant organs, resulting in death. Patients with these tumours have elevated serum calcitonin levels or are hyperresponsive to stimulation of the parafollicular cells by an infusion of calcium and a hormonal product called pentagastrin.

Medullary carcinomas of the thyroid

Early diagnosis is essential and asymptomatic family members should be checked regularly. If serum calcitonin levels are elevated or become abnormally elevated following stimulation, the patient's thyroid gland should be removed completely, followed by treatment with replacement doses of thyroxine.

Rickets, osteomalacia, and hypervitaminosis D. Vitamin D deficiency, known as rickets in children and osteomalacia in adults, was a worldwide problem, particularly in temperate zones, until the 1920s when it was found that it could be cured by exposure to light and by the administration of cod liver oil, a substance high in vitamin D. Affected individuals have soft bones, the literal meaning of the term osteomalacia. Their bones become distorted, resulting in bow legs, a bulging forehead, distortion of other bones of the head (craniotabes), and enlargement of the junctions of the ribs with the rib cartilage on the chest (rachitic rosary). These distortions are caused by the generation of excessive amounts of uncalcified bone in an attempt, in effect, to make up for the deficient calcium deposition. Healing takes place promptly with vitamin D supplements, and the disease has become rare with the irradiation of milk and other forms of preventive nutrition.

Vitamin D supplements

Osteomalacia also may be produced in patients suffering from intestinal malabsorption in which ingested vitamin D is not absorbed through the intestinal lining and then into the body. In rare instances families are afflicted with vitamin D-resistant rickets, in which enzymes for the production of the more potent vitamin D metabolites are missing, although this enzyme deficiency can be overcome by administering large doses of vitamin D. Finally, some drugs used to combat seizure disorders (phenytoin and barbiturates) may interfere with the formation of active vitamin D metabolites and thus cause osteomalacia. Because the conversion of 25-hydroxycholecalciferol to the potent derivative of vitamin D_3, 1,25-dihydroxycholecalciferol, takes place primarily in the kidney, this process is impaired in severe kidney disease. (The resulting bone disease, a form of osteomalacia, is known as renal osteodystrophy.)

Ingestion of megadoses of vitamin D produces bone disease associated with hypercalcemia. Treatment, of course, includes the discontinuance of the vitamin D supplements. Reversal of the process can be hastened by the administration of one of the cortisone family of drugs. Occasionally, as in the case of sarcoidosis, there is an abnormal sensitivity to vitamin D or an increased production of vitamin D metabolites, with the absorption of excessive amounts of calcium and the accompanying appearance of hypercalcemia. This disease, too, respond to corticosteroids.

Metabolic bone disease. While the skeleton is usually

thought of as that which is hard and unyielding in the human body, in reality living bone, like many other tissues of the body, undergoes a constant process of breakdown and renewal. This ongoing process of resorption and formation permits the skeleton to adjust to the changes required for healthy functioning, changes ranging from healing fractures to the subtle remodeling necessary to maximize bone strength following alterations in posture or gait. Normal bone provides rigid support, but at the same time it is not brittle. It consists of two major components: (1) a protein matrix consisting mostly of a fibrous protein called collagen; and (2) a mineral portion, mostly complex crystals of calcium and phosphate, which is embedded in the protein component. Bone contains nutritive cells called osteocytes, but the major metabolic activity is carried out by osteoblasts, which generate the protein matrix and osteoclasts (large, multinucleated cells that digest and dissolve bone).

Composition of bone

Only what is called metabolic bone disease, that is, disease which affects all the bones of the skeleton to a lesser or greater extent, is discussed below. These include osteoporosis, osteogenesis imperfecta, osteopetrosis, and Paget's disease of bone. For discussion of such metabolic diseases as rickets, osteomalacia, the bone disease of hyperparathyroidism, and vitamin D intoxication, see above.

The term osteoporosis, taken literally, refers to porous bone. There is simply less bone per unit volume (osteopenia) in osteoporosis. This is true despite the fact that the osteoporotic vertebral body may have collapsed on itself from pressures both from above and from below, forming what is known as a "codfish vertebra." In osteoporosis there is no difficulty with mineralization of bone; rather, the protein matrix is inadequate. There are many reasons for this change. Thinning of bones is part of the process of normal aging, but it can be much accentuated by numerous factors. Most prominent among these are the loss of estrogens in postmenopausal women; multiple forms of nutritional deficiency, including lack of dietary protein; vitamin C deficiency; alcoholism; and low calcium intake.

These deficiencies can occur not only because the required nutrients are not part of the diet but also because of any of a number of disorders associated with poor absorption of nutrients. Osteoporosis occurs rapidly in any person who becomes physically inactive, for example, paralyzed patients or those immobilized by arthritis. It can be produced by drugs such as the corticosteroids, heparin, and anticonvulsants. Estrogen deficiency is an important contributing factor, demonstrated by the fact that bone thinning occurs among those female ballet dancers and long-distance runners in whom menstruation disappears rather than in those in whom it does not. In most of these situations the rate of bone resorption exceeds that of bone formation so that, inevitably, osteopenia occurs.

Osteoporosis in postmenopausal women

Most patients with osteoporosis are women, although the disease does occur in men as well. Of the many causes of osteoporosis, by far the most common is that which occurs in the postmenopausal female. Those who are affected number in the millions, and it is estimated that approximately one-fourth of white women older than 60 years of age have some degree of osteoporosis. Many affected individuals, however, have no symptoms. Others suffer only mild back pain. As the anterior edges of the thoracic vertebra become compressed, the spine bends forward, producing the typical "dowager's hump," with an accompanying loss of height. A compression fracture of a vertebra may be signaled by a sudden, sharp pain in the affected area after minimal or no trauma. It is common, however, for the patient not to recall pain or trauma, and the vertebral fractures may be noted only as incidental X-ray findings. Fractures of the femur after little or no trauma (pathological fractures) are also quite common.

Since estrogens exert a preventive influence on the development of osteoporosis, it occurs most frequently in postmenopausal women. It is not clear why it occurs less frequently in black women than in caucasians. There is evidence that among blacks bone density at maturity is appreciably greater than among whites, so that when bone loss starts, usually several years before the onset of the menopause, those with the greatest bone density are least afflicted. Obesity also exerts a protective effect against osteoporosis, probably because adipose (fatty) tissue is capable of synthesizing estrogens.

Prevention and treatment of osteoporosis

With few exceptions the osteoporotic process (including the osteoporosis of immobilization of the young) is not reversible. The most effective measures are preventive. These include good nutrition and a liberal calcium intake throughout life, but particularly in the early postmenopausal years. Moderate, ongoing physical activity is also essential, but extraordinary long-term exercise (which may result in reduced estrogen secretion) is counterproductive. Estrogen treatment inhibits postmenopausal bone loss at least for the first several years, but whether this is advisable or necessary in all postmenopausal women is not known.

In patients already afflicted with osteoporosis, treatment with calcium, modest doses of vitamin D, or calcitriol may be helpful. Supplemental calcium fluoride also may be helpful, although occasionally at the cost of significant side effects. Again, exercise, even in the frail elderly, is considered an important component and may increase bone density.

Osteogenesis imperfecta, also known as brittle bones, is a rare inherited disease occurring in two forms. In one form, multiple fractures, particularly of the bones of the extremities, occur near the time of birth, and the death rate in afflicted infants is high. The second form is far less severe, with fractures of long bones occurring in adolescence and young adulthood. Associated abnormalities include a blue colour to the whites of the eyes (blue sclerae), along with abnormalities in heart valves. In this disorder there is an inherited defect in the formation of collagen, the protein most abundant in the organic matrix of bone and in heart valve tissue. There is no known treatment.

Osteopetrosis is another rare hereditary disease, characterized by abnormally dense bones that tend to crowd out the bone marrow. The severest form occurs in infants and was uniformly fatal until bone marrow transplantation emerged as a dramatically successful form of treatment.

Paget's disease

In a strict sense, Paget's disease is not a generalized metabolic bone disease; rather, it is a localized disease that may be disseminated to include a large portion of the skeleton. For this reason, it can be included with the metabolic disorders of bone.

The most graphic and detailed description of this disorder was provided by Sir James Paget, a prominent English surgeon. Paget believed the disease resulted from inflammation, and for this reason he called it osteitis deformans. This notion was soon discredited and many other possible causes were considered more seriously, but it now appears that Paget was correct. Under the ultramicroscope, structures that very closely resemble viruses have been seen in the osteoclasts of patients suffering from Paget's disease. The osteoclasts are extraordinarily active, digesting bone at a very rapid rate and at the same time activating a "coupling factor" that leads to a compensatory increase in bone synthesis by local osteoblasts. The result is a changed, "chaotic" bone structure leading to bone weakening and deformities.

The patient with classical, advanced Paget's disease has a large skull, a shortened spine, and bowed thighs and legs, producing a simian appearance. Pathological fractures are common, and the patient's course may be threatened by complications such as impingement of distorted vertebrae on the spinal cord, which threatens paralysis. Occasionally, the pathological stimulation of bone turnover leads to a transformation into bone cancer. There is no known cure, but the process can be suppressed effectively with a number of therapeutic agents, including salmon calcitonin, one of the diphosphonates, or plicomycin (mithramycin).

Fibrous dysplasia

Fibrous dysplasia also is a disseminated, rather than generalized, bone disease, and its cause is unknown. It may be monostotic (localized to one bone) or polyostotic. The disease leads to a gross distortion of bone structure that may result in a grotesque appearance of facial features. There are often accompanying patches of tan pigmentation (café au lait spots) and if the base of the skull is involved, particularly in females, puberty may occur at an inordinately young age (precocious puberty). (T.B.S.)

THE PANCREAS

The discovery of insulin in 1921 by a Canadian surgeon, Frederick Banting, with the assistance of a medical student, Charles Best, was one of the most dramatic events in modern medicine. It not only saved the lives of innumerable patients affected with childhood diabetes but it also ushered in present-day understanding of the complexities of the endocrine pancreas. The importance of the endocrine pancreas lies in the fact that its principal hormone, insulin, plays a central role in the regulation of energy metabolism and that a relative or absolute deficiency of insulin leads to diabetes mellitus, still a leading cause of disease and death throughout the world.

Anatomy. In humans the pancreas weighs approximately 80 grams, has roughly the configuration of an inverted smoker's pipe, and is situated in the upper abdomen. The head of the pancreas (equivalent to the bowl of the pipe) is immediately adjacent to the duodenum, while its body and tail extend across the midline nearly to the spleen. The bulk of pancreatic tissue is devoted to its exocrine function, the elaboration of digestive enzymes that are secreted via the pancreatic ducts into the duodenum.

The islets of Langerhans

The endocrine pancreas consists of the islets of Langerhans. Approximately 1,500,000 islets, weighing about one gram in total, are scattered throughout the gland. The embryonic origin of the cells that make up the islets is not clear; both endodermal and neuroectodermal precursors have been proposed. Approximately 75 percent of the cells in each islet are the insulin-secreting beta (B) cells, which tend to cluster centrally (Figure 13, top). Around the periphery lie the alpha (A), delta (D), and F (or PP) cells, which secrete glucagon, somatostatin, and pancreatic polypeptide, respectively. Each islet is supplied by one or two minute arteries that branch into numerous capillaries; from this network, capillaries emerge to coalesce into small veins outside the islet. The islets also are richly supplied with autonomic nerves. Thus, islet function may be modulated by neural control, by circulating metabolites and hormones, and by secretion of hormones locally (paracrine effects).

The principal function of the endocrine pancreas is the secretion of insulin and other polypeptide hormones necessary for the orderly cellular storage and retrieval of such dietary nutrients as glucose, amino acids, and triglycerides.

Hormones. *Insulin.* Insulin, produced by the beta cells of the islets of Langerhans, is a moderate-sized protein composed of two chains, the alpha chain (with 21 amino acids) and the beta chain (with 30), linked by sulfur atoms. Insulin is derived from a larger prohormone molecule called proinsulin. Proinsulin is relatively inactive, and normally little of it is secreted. It contains a connecting peptide, or C-peptide, composed of 31 amino acids with an additional amino acid at either end linked to the alpha and beta chains, respectively. As is the case with other prohormones, the connecting peptide of proinsulin is cleaved off before insulin is released into the circulation. Insulin leaves the pancreas through veins, which empty into the portal vein perfusing the liver. Typically the pancreas of a normal adult contains approximately 200 units (eight milligrams) of insulin; the average daily secretion of insulin into the circulation ranges between 35 and 50 units.

Proinsulin

Although a number of physiological events influence insulin secretion, the most important is the concentration of glucose in the arterial (oxygenated) blood perfusing the pancreas. When the plasma glucose level rises, insulin release is stimulated; as plasma glucose falls, so does the rate of insulin secretion. Even during prolonged fasting, however, a baseline secretion of insulin continues. Insulin secretion also is influenced by neurotransmitters interacting with islet cell receptors, particularly those that bind norepinephrine.

The action of insulin can be appreciated by considering its effect on three tissues important in metabolism (adipose tissue, muscle, and liver) and by noting the consequences of its deficiency in diabetes mellitus (see below *Diabetes mellitus*). Insulin has profound effects on adipose tissue and lipid metabolism: it permits the entry of glucose into the fat cell (adipocyte) and then stimulates the metabolism of glucose once it is in the cell. The presence of glucose within the adipocyte, in turn, leads to increased formation of fatty acids and triglycerides. Insulin has a stimulatory effect on lipoprotein lipase, an enzyme located in the walls of the capillaries in adipose tissue and one that is required for splitting circulating triglycerides, a necessary step before the fatty acid contained in triglycerides can enter fat cells. Finally, insulin is the most potent inhibitor of the release of stored fatty acids. As the level of plasma insulin rises, the release of fatty acid, or lipolysis, is markedly suppressed; conversely, as insulin falls, the release of fatty acid accelerates.

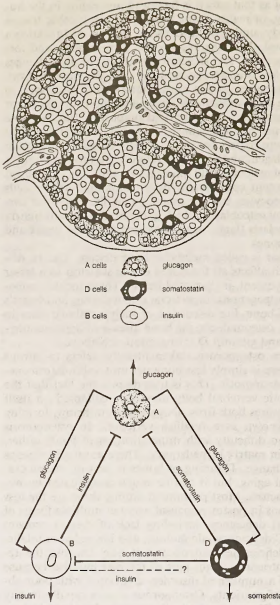


Figure 13: *Relationships of the cells of the islets of Langerhans.*
(Top) Cross-section of a normal islet. (Bottom) Possible paracrine cell–cell interactions within the islets. Stimulatory actions of the peptides on the neighbouring cells are represented by long arrows; inhibitory actions are represented by short bars. Endocrine secretion into the circulation is shown by short arrows.
From R.H. Unger and L. Orci, *New England Journal of Medicine*, vol. 304, p. 1518 (1981); reprinted by permission of the *New England Journal of Medicine*.

Insulin stimulates the transport of glucose and amino acids into muscle cells and prompts the conversion of amino acids into protein. Thus, insulin is required to replete the glycogen, a stored form of glucose, that is oxidized during exercise and to replenish protein needed for muscle growth and repair. Insulin is not required for the transport of glucose into liver cells, but the hormone profoundly affects intracellular metabolism in the liver. It promotes glycogen formation, stimulates the utilization of glucose, and suppresses those enzymes necessary for new glucose formation (gluconeogenesis) and glycogen breakdown (glycogenolysis). The overall effect of insulin is to increase glucose utilization and storage and decrease its release by the liver.

Overall effect of insulin

Glucagon. Glucagon is produced by the alpha cells

of the pancreas and also is secreted by cells scattered throughout the gastrointestinal tract. A number of forms of glucagon have been found; the biologically active one appears to contain 29 amino acids. Radioimmunoassays can distinguish between pancreatic glucagon and similar peptides from the gut. Circulating glucagon levels are high in the fasting state. Secretion is stimulated by amino acids and gastrointestinal peptide hormones. Normally, ingested glucose is a potent suppressor of glucagon release, an effect that is probably mediated by an increase in circulating insulin. Secretion of glucagon also is inhibited by free fatty acids and by somatostatin and appears to be modulated by the autonomic nervous system. Circulating glucagon binds to specific receptors on the surface of liver cells (hepatocytes), leading to the breakdown of liver glycogen into glucose, which is then released into the blood. Glucagon is estimated to be responsible for most of the hepatic glucose production after an overnight fast.

Somatostatin. Somatostatin, a peptide that was discovered initially in the hypothalamus (see above *Hypothalamus: Growth hormone-releasing hormone*), contains 14 amino acids, is produced by the D cells of the islets, and has a number of effects on digestion. It inhibits gastrointestinal motility and blood flow, secretion of stomach acid, secretion of pancreatic exocrine, and the absorption of triglyceride from the bowel.

Effects of pancreatic hormones

In summary, it appears that the hormones insulin, glucagon, and somatostatin act in concert to control the flow of nutrients into and out of the circulation. The relative concentrations of these hormones regulate the rates of absorption and peripheral disposal of substances such as glucose, amino acids, and fatty acids. The anatomic proximity of the B, A, and D cells in the islets is significant. Somatostatin and glucagon appear to have a paracrine relationship whereby they influence the secretion of each other, and both affect the rate of insulin release (Figure 13, bottom).

Pancreatic polypeptide. Pancreatic polypeptide, secreted by the F (or PP) cells, contains 36 amino acids. Circulating levels rise following ingestion of a meal. An increase in the level of free fatty acids in the blood suppresses its secretion. Pancreatic polypeptide can inhibit gallbladder contraction and pancreatic exocrine secretion, but its biologic role is uncertain.

Hormonal control of energy metabolism. The functions of the pancreatic hormones, particularly insulin and glucagon, can best be appreciated by considering their roles in maintaining glucose homeostasis and in regulating nutrient storage. An adequate supply of glucose is required for optimal body growth and development and for the health of the central nervous system, for which glucose is the major (and usually the only) source of energy. It is not surprising, therefore, that elaborate mechanisms have evolved to ensure that a normal plasma glucose level is maintained regardless of whether a person is feasting or fasting. Another requirement for survival is the ability of the body to store excess nutrient fuel for recall and use during periods of scarcity. Adipose tissue serves this need. Compared to carbohydrate and protein, fat yields twice the calories per gram. Furthermore, adipose tissue contains less than 10 percent water. Thus, a kilogram of fat has 10 times the caloric value of a portion of muscle of the same weight. Following the ingestion of a meal, the carbohydrate content is assimilated as glucose, leading to an elevation in blood glucose and to an increase in plasma insulin from 10 microunits per millilitre to 50–100 microunits per millilitre. This high level of insulin promotes glucose uptake by the liver, adipose tissue, and muscle. Fatty acids and amino acids derived from the digestion of fat and protein are also deposited in the liver and peripheral tissues. Glucose production by the liver is inhibited, and brain metabolism is fueled by dietary glucose. Insulin also suppresses lipolysis so that the concentration of free fatty acids in the plasma falls. Thus, the "fed," or anabolic, state is characterized by nutrient storage dependent on an increase in circulating insulin.

The anabolic state

Within a few hours after a meal, when gastrointestinal absorption of nutrients is complete, the level of insulin falls and hepatic production of glucose resumes, sustaining the needs of the brain. Similarly, lipolysis increases, providing fuel for muscle. After a longer period of fasting, (*e.g.,* 12 to 14 hours or overnight), the insulin level falls still lower and plasma glucagon increases. Hepatic glycogen becomes depleted, and glucose production is achieved by gluconeogenesis, a process requiring precursor carbon molecules such as the amino acid alanine from muscle breakdown and glycerol from lipolysis. Thus, the "fasting," or catabolic, state is characterized by a low level of insulin, an increased concentration of glucagon, and a withdrawal of stored nutrients.

With further fasting, lipolysis continues to increase for a few days before it plateaus at a high rate. A large proportion of elevated fatty acids are converted to the "ketone bodies" in the liver, a process enhanced by the high level of glucagon. The brain, previously an avid and fastidious consumer of glucose, begins to use ketones as well as glucose. Eventually, more than one-half of the brain's daily metabolic energy needs are met by the ketone bodies, thus substantially diminishing the need for hepatic glucose production. The decrease in gluconeogenesis reduces the need for protein-derived amino acids, sparing muscle and making survival during prolonged fasting possible. Starvation is characterized by very low levels of insulin, elevated concentrations of glucagon, and very high concentration of circulating free fatty acids and ketones.

Insulin actions

In summary, in the fed state insulin mediates (1) the transport of glucose into body tissues (to be consumed as fuel or stored as glycogen), (2) the transport of amino acids into tissues (to build or replace protein), and (3) the transport of glucose and fatty acids into adipose tissue (to provide a fuel depot for future energy needs). During fasting, insulin levels are depressed and the opposite sequence of events occurs, modulated by glucagon and other "anti-insulin" hormones such as cortisol from the adrenal cortex.

Diseases and disorders. *Diabetes mellitus.* A relative or absolute deficiency of insulin results in the disease diabetes mellitus, by far the most common disorder of the endocrine system. The number of individuals with diabetes doubles every 15 years. While insulin, discovered by Banting and Best in 1921, can prevent early death from diabetic coma, insulin treatment does not prevent the chronic, disabling complications of the disease. Statisticians list diabetes mellitus among the top 10 causes of death in the United States, for example, and cite it as the leading cause of blindness and uremia.

Types of diabetes

In the United States, the National Institutes of Health has classified diabetes into a number of types. Type I, or insulin-dependent diabetes mellitus (IDDM), formerly termed juvenile-onset diabetes, can occur at any age of life. Affected individuals have insulin deficiency due to islet cell loss and may become comatose when exogenous insulin is withheld. Type II, or non-insulin-dependent diabetes mellitus (NIDDM), previously called maturity-onset diabetes, also can occur at any age but is most common in adults. Affected individuals are not prone to coma except in the presence of stress, although they often require insulin to control hyperglycemia. The majority are obese. Other types are a miscellaneous group, formerly called secondary diabetes, and include diseases attacking the pancreas (*e.g.,* hemochromatosis, pancreatitis), and syndromes characterized by insulin antagonism (*e.g.,* Cushing's disease, acromegaly). The term impaired glucose tolerance (IGT) is applied to those who have oral glucose tolerance tests (OGTT) that exceed normal levels but are not sufficiently abnormal to justify the diagnosis of diabetes mellitus. Most of these individuals do not progress to overt diabetes and do not develop the chronic complications of the disease. The term gestational diabetes mellitus (GDM) is reserved for diabetes or glucose intolerance that develops, or is first recognized, during pregnancy. Patients usually revert to normal glucose tolerance following pregnancy.

In order to diagnose diabetes mellitus in an apparently healthy adult, a physician must observe either two fasting plasma glucose values greater than 140 milligrams per decilitre or any two values greater than 200 milligrams per decilitre following a 75-gram oral glucose load. Criteria

for the diagnosis of glucose intolerance include a fasting plasma glucose value between 115 and 140 milligrams per decilitre, a two-hour postprandial value between 140 and 200 milligrams per decilitre, and at least one value greater than 200 milligrams per decilitre during a standard oral glucose tolerance test.

Causes of diabetes

It seems likely that there are two distinct causes for IDDM and NIDDM. A genetic factor appears to be more important in NIDDM, since analysis of a large series of identical twins has shown a concordance (the appearance of the trait) in both twins of more than 90 percent for NIDDM, while in IDDM the rate is about 50 percent. This relatively low incidence of the disease among the identical twins of insulin-dependent diabetics suggests that other factors are important. One such factor may be immune-related. Among insulin-dependent diabetics, there is a relatively high prevalence of certain patterns of the inherited tissue compatibility antigens (HLA), while in NIDDM the prevalence of these HLA types is normal. In addition, there is a high prevalence of autoantibodies to islet cells found in the sera of insulin-dependent diabetics, along with inflammation of the islets. There is evidence that in some cases of IDDM, viral infections may play a role. Coxsackie virus B_4 has been isolated from the pancreas of a child who died accidentally shortly after the onset of diabetes. This virus was cultured and found to cause beta cell damage when injected into mice. Further evidence for an infectious factor in the causation of type I diabetes mellitus is the seasonal appearance of new cases of the disease.

Viral and autoimmune factors

It may be that viral and autoimmune factors combine to cause diabetes, the viral infection of the pancreas leading to the release of proteins into the circulation that are recognized as foreign by the victim's immune system. In this theory, autoantibodies cause destruction of the beta cells of the pancreas. This thesis suggests the possibility of preventing the disease either by immunization against suspect viruses or early treatment with immunosuppressive drugs. Patients with NIDDM appear to suffer from resistance to insulin along with abnormal secretion of the hormone. In fact, these patients may initially have higher than normal concentrations of plasma insulin. The primary site of resistance is likely to be within the cell (*i.e.,* a postreceptor defect), although a receptor abnormality may also be implicated. In many, but not all type II patients, resistance to insulin is linked to obesity.

A relative or absolute deficiency of insulin results in hyperglycemia, the central biochemical feature of the disease. Hyperglycemia ensues because of impaired transport of glucose into muscle and adipose tissue and the increased release of glucose into the circulation by the liver. Above a glucose concentration of about 180 milligrams per decilitre the kidney tubules are unable to reabsorb all of the glucose filtered by the glomeruli. The excretion of glucose by the kidney requires a simultaneous movement of water out of the plasma and into the kidney, from which it is excreted. The subsequent increase in the relative concentration of solutes in the water-depleted plasma in turn stimulates the thirst centres of the hypothalamus in the brain. Three classic conditions thus result: polyuria (excretion of a large volume of urine in a specific amount of time); polydipsia (excessive, long-term thirst); and polyphagia (voracious eating). All can be explained in terms of the body's loss of large quantities of glucose and water, which results in a compensatory increase in hunger and thirst. With more severe insulin deficiency, hyperglycemia and glycosuria intensify, liquid intake falls behind urinary loss, and dehydration and shock ensue. The rate of fatty acid release from adipose tissue is greatly accelerated. Much of the fatty acid reaching the liver is converted to the ketone bodies acetoacetic acid and beta-hydroxybutyric acid. Both substances lower the pH of the blood, normally held at a pH of 7.4. As the acidic state progresses, there is depression of cerebral and myocardial function, culminating in coma and death. Appropriate fluid therapy and administration of insulin is life saving. The blood sugar is lowered, dehydration and shock are reversed, and the blood pH is restored to normal.

Prolonged survival of patients with diabetes mellitus has led to an increasing incidence of chronic complications, most of which can be explained by changes in the patient's blood vessels. Small blood vessel disease (microangiopathy) is unique to diabetes; the principal feature seen under the microscope is thickening of the walls of the capillaries. With time, affected capillaries become leaky, leading to changes in the retina (retinopathy) and kidney (nephropathy). Ultimately, there may be retinal hemorrhage leading to blindness and severe impairment of renal function causing uremia. Diabetic patients are also afflicted by an increased incidence of large vessel disease. Microscopically, hardening of the arteries (atherosclerosis) in the diabetic is not different from that seen in nondiabetic individuals; however, it occurs earlier and progresses faster in diabetic patients. Premature coronary artery disease is a common cause of death among diabetics. The large arteries of the lower extremities are often affected, contributing to the high incidence of foot ulceration and gangrene and resulting in amputation.

Complications of diabetes

Not all complications are directly related to vascular disease. Early cataract formation, impaired function of the autonomic nervous system, and peripheral nerve damage (neuropathy) cannot be fully explained by blood vessel changes. Autonomic nervous system dysfunction may be manifested by gastric retention, chronic diarrhea, incomplete emptying of the bladder, impotence, and low blood pressure when standing. Diabetic neuropathy often affects the lower extremities, causing either loss of feeling or disagreeable sensations of burning or itching. It is not known if these complications are due to long-standing hyperglycemia and insulin deficiency or are caused, at least in part, by an unidentified factor.

Treatment of diabetes

There are three basic components in the treatment of IDDM: insulin, diet, and exercise. Insulin is prepared in a number of forms, providing short, intermediate, and long actions to accommodate the specific needs of individual patients. Sources of insulin traditionally have been from pork and beef pancreases, but insulin with a structure identical to that produced by human islets is now widely available. It is either synthesized using recombinant DNA technology or prepared by the chemical alteration of porcine insulin. Insulin is given by one or more injections each day or by continuous infusion using an insulin pump, a computerized device the size of a deck of cards, which is worn by the patient and delivers a preset amount of hormone throughout the day. A typical diabetic diet contains sufficient total calories to maintain ideal body weight and consists of carbohydrate, fat, and protein and of ample fibre. Simple sugars and alcohol are prohibited. Compared to insulin and diet, exercise is more difficult to measure. Ideally, the diabetic exercises a fixed amount each day, and insulin and diet are tailored to accommodate that amount.

The goals of treatment include maintenance of the blood sugar near or within normal limits, freedom from hypoglycemia, and an acceptable life-style. The blood sugar usually can be monitored at home by the patient. Measurement of that portion of hemoglobin complexed to glucose provides another index of the adequacy of blood sugar control. Proteins exposed to glucose-containing solutions undergo glycosylation (*i.e.,* a certain number of glucose molecules become irreversibly fixed to the protein molecule). The higher the glucose concentration, the greater the degree of glycosylation. In normal humans approximately 6 percent of circulating hemoglobin is glycosylated; in poorly controlled diabetics, the figure may be 14 percent or more. Glycosylation of structural proteins, such as those in the basement membranes of capillaries, may play a role in the pathogenesis of the chronic complications of diabetes.

In the treatment of NIDDM, diet and exercise again are important. In the obese patient, evidence of diabetes mellitus may disappear if the patient can achieve and maintain ideal body weight. Insulin or a blood-sugar-lowering drug, however, may be required to control blood sugar.

Hypoglycemia. Although a wide array of human ills are attributed to low blood sugar (hypoglycemia), well-documented hypoglycemia is not common except among insulin-dependent diabetics. Regardless of the underlying

cause, the manifestations of hypoglycemia evolve in a characteristic pattern. Mild hypoglycemia causes hunger, fatigue, tremor, perspiration, weakness, and anxiety. These same symptoms often appear in a variety of conditions other than hypoglycemia, however. To implicate hypoglycemia properly, such symptoms should be associated with a blood glucose of less than 40 milligrams per deciliter and be promptly relieved by the administration of glucose. More severe hypoglycemia leads to blurred vision, impaired mentation, and bizarre behaviour. A staggering gait and irrational, hostile behaviour are frequently misinterpreted as drunkenness. Finally, the patient becomes comatose and may develop generalized seizures. If severe hypoglycemia remains untreated, permanent brain damage or death can result.

The principal causes of hypoglycemia can be grouped into two large categories: fasting and fed (or "reactive"). The time of day at which hypoglycemia occurs provides a clue to the underlying cause. Since liver production sustains the blood glucose level during periods of fasting, rare, inherited disorders that cause impairment in glycogen storage or gluconeogenesis lead to fasting hypoglycemia. This typically occurs in the early morning hours after eight or nine hours of fasting. Fasting hypoglycemia is also caused by insulin-secreting islet cell adenomas. In these cases, hypoglycemia is prevented during the waking hours by frequent eating, leading to weight gain.

Reactive hypoglycemias

Far more common are the reactive hypoglycemias, triggered by the assimilation of glucose following a meal. Normally, the secretion of insulin is commensurate with the degree of postprandial elevation of the blood sugar. After surgery that impairs the reservoir function of the stomach, ingested glucose is dumped into the duodenum and upper jejunum, where it is rapidly absorbed. The resulting excessive hyperglycemia stimulates a brisk release of insulin, leading to moderately severe hypoglycemia within two hours of the meal. There is another group of patients who assimilate glucose at an excessive rate even though they have not had gastrointestinal surgery. Such individuals typically have symptoms three to four hours after the ingestion of a large quantity of glucose. Manifestations of hypoglycemia usually can be avoided in reactive hypoglycemia by restricting the amount of glucose in the diet. The most frequent cause of clinically significant hypoglycemia is self-administration of insulin by the diabetic patient. This may result from an excessive dose of insulin, inadequate dietary amounts, or excessive physical activity. Rarely, hypoglycemia may be self-induced by emotionally disturbed patients with access to insulin.

Tumours of the pancreas. Inappropriate hypersecretion of pancreatic hormones may be due to diffuse hyperplasia (abnormal multiplication) of the secretory cells, adenomas (benign tumours), or carcinomas (malignant tumours). Hypersecretion of insulin is most frequently due to a single insulin-producing adenoma. Single or multiple insulinomas may occur as part of the syndrome of multiple endocrine neoplasia. Malignant insulinomas are less common. Diffuse hyperplasia of beta cells (nesidioblastosis) may cause hypoglycemia in infants. Glucagon-secreting tumours (glucagonomas) produce the "diabetes-dermatitis syndrome." Patients have mild diabetes, anemia, and a red, blistering rash that appears in one area of the body and then fades, only to reappear at a different site. Patients have elevated plasma glucagon levels, but marked hyperglycemia is prevented by an offsetting increase in insulin secretion.

Somatostatin-producing tumours are difficult to diagnose because findings are nonspecific and include diabetes mellitus, gallstones, excessive fat in the stool, indigestion, and diminished secretion of gastric acid. Plasma somatostatin levels are increased when measured by radioimmunoassay, and both insulin and glucagon concentrations are decreased. Pancreatic polypeptide-secreting islet cell tumours have been found in patients with the syndrome of multiple endocrine neoplasia. Pancreatic tumours may also be the source of "ectopic" hormone secretions (in which a hormone is secreted from a tissue type that normally does not secrete it; see below *Ectopic hormone and polyglandular disorders*). (T.W.B.)

THE ADRENAL CORTEX

Anatomy. The adrenal glands lie on the upper inner surface of each kidney. Each gland consists of two parts that are quite distinct anatomically, embryologically, and functionally. The inner core (adrenal medulla) is discussed separately below. The outer covering (adrenal cortex) is derived from the fetal mesodermal ridge, a structure that also gives rise to the kidneys so that the juxtaposition of the two organs is not surprising. Within the adrenal cortex are three zones known as the outer (zona glomerulosa), the middle (zona fasciculata), and the inner (zona reticularis). Under the microscope the cells are rather typical endocrine cells; the distinction between zones is made by differing staining characteristics.

The zones of the cortex

Hormones. Adrenocortical cells synthesize and secrete chemical derivatives (steroids) from cholesterol, the major animal sterol. While cholesterol can be synthesized in many body tissues, further differentiation into steroid hormones takes place only in the adrenal cortex and in its embryological cousins, the ovaries and the testes.

The adrenal cortex is capable of synthesizing all of the steroid hormones produced by the body, including the progestogens and estrogens (see below *The ovary*), androgens (see below *The testis*), mineralocorticoids (which are secreted from the zona glomerulosa), and glucocorticoids (which are synthesized and released from the zona fasciculata and zona reticularis of the adrenal cortex). Although upwards of 60 steroids are manufactured in the adrenal cortex, only a few members of these three major categories are important in body functioning.

Aldosterone. The biologic effect of aldosterone, the principal mineralocorticoid produced by the zona glomerulosa, is to set in motion a set of reactions at the cell surface of all body tissues in order to enhance the uptake and retention of sodium in all cells and the extrusion of potassium from them. Such fluxes of sodium and potassium following the administration of aldosterone are detectable even in glandular secretions, such as sweat. It also has a major impact on kidney function, acting on the renal tubules to retain sodium within the circulation while increasing the excretion of potassium into the urine. At the same time, by increasing the reabsorption of bicarbonate by the kidney, aldosterone tends to decrease the acidity of body fluids.

Cortisol. Cortisol (hydrocortisone) is the major human glucocorticoid. It exerts multiple and varied effects. It also serves as a mineralocorticoid but is considerably less effective than aldosterone. Cortisol plays a major role in the body's response to stress. In fasting, for example, it sustains the blood sugar concentration by blocking the egress of glucose into all tissues other than the critically important brain and spinal cord, while it simultaneously increases the breakdown of protein from muscle and other organs and hastens the conversion of newly generated amino acids to glucose to replenish the supply constantly being consumed by the brain.

"Permissive" actions

In addition, glucocorticoids have a "permissive" action for many chemical reactions in the body; that is, their presence is necessary for the action to occur, but they themselves do not initiate it. For example, the secretion of acid into the stomach does not occur in the total absence of glucocorticoids, but, in the presence of normal amounts of cortisol, acid can be excreted in small or large amounts as the body requires.

Cortisol, along with more potent and longer-acting synthetic derivatives like prednisone, methylprednisolone, and dexamethasone exerts powerful anti-inflammatory effects. Physicians take advantage of these properties in treating patients with serious inflammatory illnesses such as rheumatoid arthritis, disseminated lupus erythematosus, and multiple sclerosis. If, however, the inflammation has a bacterial or viral origin, the steroids may do more harm than good because the spread of the infection is facilitated while the signs of inflammation are masked (see IMMUNITY). Finally, corticosteroids in large doses impair the functioning of the immune system so that the production of harmful antibodies, such as those produced in allergic diseases, may be suppressed. It is important to note that these beneficial effects are offset by serious side effects

of large-dose, long-term corticosteroid therapy, effects that closely mimic many of the symptoms of Cushing's syndrome (see below).

Adrenal androgens. Ordinarily, adrenal estrogens do not play an important role in the body's economy, but adrenal androgens do make a significant contribution. These androgens are not as potent as testosterone, the major steroid secreted by the testis, but a number of them, including androstenedione, dehydroepiandrosterone (DHEA), and its sulfate (DHEAS) may be converted to stronger androgens such as testosterone. Although little androgen is secreted before puberty, the output increases dramatically at puberty so that the adrenal cortex makes a significant contribution, known as the adrenarche, to developmental changes in both sexes.

All steroid hormones, including those from the adrenal cortex, are bound to steroid-binding globulins (transcortin) in the circulation and are released at the surface of a target cell. The steroid passes into the cell cytoplasm and is bound to an intracellular binding protein and thence is transported into the cell nucleus. There the hormone exerts its effect by modulating gene activity so that the synthesis of some proteins is stimulated while that of others might be inhibited. The net effect is the biologic action noted at the physiological or pathological level. The steroid hormones undergo inactivation in a complex series of transformations principally in the liver but in other tissues as well, leading to a total loss of hormonal activity.

Regulation of corticosteroids

Regulation of hormone secretion. The three classes of corticosteroids (the mineralocorticoids, the glucocorticoids, and the adrenal androgens) are regulated largely by separate mechanisms. Glucocorticoids are regulated by way of the classical hypothalamic-hypophyseal feedback system shown in Figure 3. Within the family of glucocorticoids, the cortisol level is the one most closely guarded. Furthermore, the ongoing feedback control is modulated by hypothalamic biorhythmic activity illustrated in the case of cortisol in Figure 9. When the individual is exposed to physical or emotional stress, the self-regulating mechanism is interrupted and plasma cortisol is increased to deal with the stress. Adrenal androgen secretion is controlled primarily by ACTH, although there is evidence that prolactin stimulates the secretion of adrenal androgens as well.

Aldosterone secretion is modulated directly by serum electrolyte levels. Lowered serum sodium concentrations enhance aldosterone secretion, but a far more potent stimulus is a high serum potassium level.

A major regulator of aldosterone secretion is the renin-angiotensin system, although ACTH also stimulates mineralocorticoid secretion. Renin is an enzyme secreted into the blood plasma from specialized cells encircling the arteriole located at the entrance to the glomerulus (the renal capillary network that is the filtration unit of the kidney). Renin secretion is inhibited when these cells, contained in what is known as the juxtaglomerular apparatus, are compressed by dilatation of this entering (afferent) arteriole provoked by an increase in plasma volume. When plasma volume decreases, renin secretion is stimulated.

Renin catalyzes the conversion of a plasma protein, angiotensinogen, into an active decapeptide, angiotensin. Angiotensin is a potent stimulator of arteriole constriction and aldosterone secretion. Both actions result in higher blood pressure, the first by increasing resistance to the flow of blood ejected by the heart, and the second by increasing total plasma volume. These are key responses when blood pressure falls to a dangerously low level. On the other hand, excessive renin secretion can lead to ongoing high blood pressure with its dangerous consequences to the health of the patient.

For a number of years investigators have sought a factor secreted by the hypothalamus that would specifically modulate aldosterone secretion in the same negative feedback fashion that relates pituitary corticotropin to the adrenocortical glucocorticoid, cortisol. Several candidates, including melanotropin (MSH) and endorphins, have emerged. Whether either or both of these hormones completely fulfill this role remains uncertain.

More recently, a new group of factors, the atrial natriuretic (sodium-excreting) peptides (atriopeptin, atrin), have been characterized. These hormones are secreted into the blood when the upper chambers of the heart, the atria, are stretched by an expanded volume of blood. The major polypeptide isolated from human atria, atrin, contains 28 amino acids. In general, the actions of atrin oppose those of angiotensin; atrin blocks the contractions of muscles in the walls of arteries so that the arteries dilate, and atrin inhibits the synthesis and secretion of aldosterone. Furthermore, it inhibits the release of renin from the juxtaglomerular cells, and finally it acts directly on the kidney to increase the excretion not only of urine but also the sodium chloride, potassium, magnesium, and phosphorus contained in it. This powerful natriuretic action may have important therapeutic applications in patients with heart failure, high blood pressure, liver disease, or other illnesses associated with the retention of fluid. Finally, it should be noted that the adrenal glands are influenced not only by endocrine factors but also by neural influences. The neurotransmitter dopamine is a powerful suppressor of aldosterone secretion, while serotonin may have a stimulating effect.

Atrial natriuretic peptides

Diseases and disorders. *Adrenal insufficiency (Addison's disease).* Adrenal insufficiency is a rare disease. In the past it was caused most commonly by destruction of both adrenals in tuberculosis patients. More recently, it has been found that destructive autoantibodies are most often the cause, sometimes as part of the inherited syndrome of multiple endocrine deficiencies (see below *Ectopic hormones and polyglandular disorders*). Other infectious diseases such as histoplasmosis may also destroy both adrenals. The adrenal glands may be involved in many other pathological processes (for instance, invasion by cancer), but adrenal insufficiency does not supervene because more than 90 percent of the total of adrenal cortical tissue must be destroyed before it becomes incapable of providing for the body's needs. Adrenal insufficiency may be secondary to diseases of the pituitary or hypothalamus, resulting in deficiencies of corticotropin or CRH, respectively.

Addison's disease

Addison's disease, if undiagnosed, leads to death. The onset of Addison's disease is often gradual and puzzling to both patient and physician. There is an increasingly generalized weakness along with an inordinate tiredness after physical activity. The patient loses appetite and weight and suffers occasional bouts of vomiting and diarrhea. There is increasing pigmentation, not only in exposed areas but also in the nails and in the skin creases. The patient's blood pressure falls, and there may be episodes of fainting upon arising from bed or from a chair. The patient must eat regularly because even minor delays result in hypoglycemic episodes. If the disease is caused by an infectious agent, there may be calcification in the area of the adrenals seen on X-ray examination of the abdomen.

The symptoms intensify over a period of months until, either spontaneously or as the result of physical stress, such as trauma or an intercurrent illness, the patient suffers acute adrenal insufficiency, known as Addisonian crisis, and experiences a catastrophic change in status. With intensified vomiting, diarrhea, and fever and with a precipitous fall in blood pressure, the patient goes into shock and dies.

Addisonian crisis may occur also in individuals who have no previous adrenal disease. During or shortly after birth some infants suffer bilateral massive adrenal hemorrhage. A similarly destructive hemorrhage can occur in adults, especially those who are treated with anticoagulants like heparin and undergo an operation or other trauma. Cortisol given intravenously is life-saving.

In chronic adrenal deficiency the patient can be kept alive and well with modest doses of cortisol taken orally, often along with a synthetic mineralocorticoid. Occasionally, salt tablet supplements are useful. The dosage must be sharply increased during periods of acute illness or injury. Before the advent of these simple therapeutic measures patients with Addison's disease died within two to three years after diagnosis. Such patients can now look forward to a full life span as long as they are prepared to increase the dosage of cortisol in the event of serious physical stress.

Hypercorticism (Cushing's syndrome). Hypercorticism, the illness resulting from overactivity of the adrenal cortex, exemplifies nicely the medical term syndrome, a constellation of symptoms and signs that together makes up a specific, easily recognized clinical entity, but which has diverse causes. In 1932, the American Harvey Cushing, a pioneer in the field of neurosurgery, described the clinical picture of patients harbouring a specific type of pituitary tumour, an entity that became known as Cushing's disease.

Further studies over the years have revealed that, with minor variations, the clinical picture described by Cushing could also result from at least four other causes: a benign tumour or a cancer of the adrenal cortex; a corticotropin-releasing, hormone-producing hamartoma of the hypothalamus; a number of tumours, both benign and malignant, that ordinarily do not secrete hormones (ectopic hormones that then produce tumours); and finally, the therapeutic administration of large doses of adrenocortical hormones (iatrogenic, or physician-induced, Cushing's syndrome). Thus, ordinarily, the clinician first makes the diagnosis of Cushing's syndrome and then explores further to determine the specific cause so that appropriate, specific treatment can be administered.

Causes of Cushing's syndrome

Cushing's disease results from a hyperfunctioning, corticotropin-producing, benign (rarely malignant) tumour of pituitary corticotrophs. Secreted along with corticotropin is melanotropin (MSH) so that the patient becomes progressively pigmented in a fashion similar to what is seen in patients with Addison's disease. For reasons poorly understood, the patient gains weight in a peculiar distribution; the obesity is confined to the central body areas—the abdomen and back and buttocks—with rather thin extremities. Excess fat deposits occur at both temples, giving rise to a "moon face," and fat may be deposited in the anterior neck ("dewlap"), below the neck posteriorly ("buffalo hump"), around the heart, and even in the spinal canal. Most of the symptoms result from the powerful protein catabolic and gluconeogenetic effects of the glucocorticoids. All patients show progressive weakness and muscle wasting. The skin becomes thin and fragile so that hemorrhages beneath the skin occur frequently. The bone becomes osteoporotic. The increased glucose production may lead to diabetes mellitus as an additional complication. Finally, in women, ovulation is suppressed and there is often amenorrhea along with hirsutism (hairiness), the result of increased adrenal androgen secretion.

Treatment

Treatment is directed against the specific cause. Pituitary tumours are removed surgically, and recurrences may be treated with X-ray therapy. Adrenal tumours also are removed surgically. Adrenocortical carcinomas usually carry a grave prognosis; initially they are treated by surgical removal unless they have already metastasized, in which case a number of drugs are available that block the secretion of corticosteroids. In addition, drugs have been introduced that block the peripheral action of glucocorticoids by displacing them from the specific receptors. Ectopic corticotropin-producing tumours are treated either by surgery, X-ray therapy, or chemotherapy. Occasionally, if the Cushing's syndrome becomes life-threatening and the usual forms of therapy have been unsuccessful, both adrenal glands may have to be removed. The ensuing adrenal insufficiency is treated in a fashion similar to that in patients with Addison's disease. In those patients in whom the primary cause is a pituitary tumour, bilateral adrenalectomy is sometimes followed by a rapid progression in growth of the tumour along with intense skin pigmentation, a combination known as Nelson's syndrome.

Hypoaldosteronism. Total destruction of the adrenal glands by definition includes hypoaldosteronism as part of the disorder. There exists, however, a disease in which adrenocortical function is intact except for defective synthesis and secretion of aldosterone from the zona glomerulosa.

Isolated aldosterone deficiency results in a low level of sodium in the serum (hyponatremia) along with an elevated level of potassium (hyperkalemia). These biochemical changes produce weakness as well as an increased risk of dangerous abnormalities in heart rhythm, some of which are fatal. Hypoaldosteronism is frequently associated with kidney disease, especially in diabetics, and in these instances the cause stems from deficient production of renin with consequent low levels of angiotensin and a reduced stimulus for the secretion of aldosterone. Rarely, the deficiency lies in an inadequate production of the enzyme needed to synthesize angiotensin (angiotensin-converting enzyme). As a result, plasma renin levels are elevated. In other cases there is an enzymic defect in aldosterone production, which may be hereditary. Treatment requires the administration of fludrocortisone, a powerful synthetic mineralocorticoid. Aldosterone itself is poorly absorbed when taken orally.

Hyperaldosteronism (Conn's syndrome). In 1955, an American internist, Jerome Conn, described a form of high blood pressure associated with hypokalemia and reduced acidity of the blood (alkalosis) in patients who harboured a benign tumour of adrenal glomerulosa cells. These patients were found to have high levels of aldosterone in the circulation, and for most the hypertension and hypokalemia disappeared with the removal of the adrenal adenoma. Aside from the sometimes severe symptoms of high blood pressure, such as headache, patients often note weakness, increased urination, increased thirst, and peculiar skin sensations along with muscle cramping. Abnormalities in heart rhythm also may occur, and if potassium loss is severe there may be impaired glucose tolerance, although diabetes is not common.

Symptoms of Conn's disease

Hyperaldosteronism may occur as a secondary phenomenon in other diseases, particularly those accompanied by increases in extracellular fluid (edema). Examples include heart failure, severe liver disease, and a kidney ailment, nephrosis, characterized by excessive loss of plasma proteins. While the cause of increased aldosterone secretion in these illnesses is not clearly understood, successful treatment of the primary disease leads to a restoration of aldosterone levels to normal.

An American endocrinologist, Frederic Bartter, described individuals who exhibited hyperplasia of the juxtaglomerular apparatus, high serum renin and angiotensin levels with resultant elevations in plasma aldosterone associated with hypokalemic alkalosis. These individuals, however, had a consistently normal blood pressure. The onset is usually in late infancy or childhood, and patients often show evidence of dwarfism and mental retardation. The cause is not well understood, but the hypokalemia and some of the symptoms may be reversed by the use of drugs, such as indomethacin, that inhibit the formation of prostaglandins.

Congenital adrenal hyperplasia. Congenital adrenal hyperplasia is a disorder in which the hereditary absence of a single enzyme has far-reaching consequences. In the most common form of this deficiency, an adrenal enzyme called 21-hydroxylase is absent. As a result, the adrenals cannot synthesize aldosterone and cortisol. The low levels of circulating cortisol reduce inhibition of corticotropin secretion by the pituitary. The resulting high levels of corticotropin lead to excessive secretion of adrenal androgens. When this enzyme deficiency is absolute, the child may die at, or soon after, birth from adrenal insufficiency. When the enzyme deficiency is only partial, the child may survive. Because the excess of adrenal androgens begins in utero, however, children are born with striking signs of masculinization (virilization): newborn genetic females have an enlarged clitoris, often mistaken for a penis, and an enlarged vulva, which resembles a bilobed scrotum. These individuals, known as female pseudohermaphrodites, may reach maturity and live out their lives as short, stocky males. They are, of course, infertile since they have vestigial ovaries rather than testes. A variation on this disorder occurs late in adolescence and is diagnosed in women who appear normal except for the development of excessive hair on the face and extremities (hirsutism). In genetic males, the excessive androgens lead to striking muscle development and an enlarged penis, the "infant Hercules."

21-hydroxylase deficiency

Treatment of the juvenile form of this disorder depends upon the time of diagnosis. If the patient is near the age of puberty, it is generally considered wise to permit the genetic female to maintain the male gender role since it has become deeply embedded. When the diagnosis is

made at birth, however, treatment with replacement doses of cortisol permit a reversal of the entire process. Normal levels of cortisol reduce the excessive secretion of corticotropin, which in turn decreases the secretion of male sex hormones (adrenal androgens) to normal. The patient then develops normally, and the ambiguous genitalia can be corrected surgically. For the late-onset type, treatment with cortisol or one of the synthetic glucocorticoids arrests the process.

Other enzyme deficiencies in adrenal hyperplasia result in still other dramatic variations. The absence of 17α-hydroxylase leads to a stockpiling of steroid precursors, sometimes including a powerful mineralocorticoid called desoxycorticosterone. The result in a child is similar to that seen in primary aldosteronism (hyperaldosteronism) with hypertension and hypokalemic alkalosis. Another genetic defect, 18-hydroxylase deficiency, blocks the formation of aldosterone so that the child shows evidence of mineralocorticoid deficiency, excreting excessive amounts of salt. This is a hereditary form of hyperaldosteronism. These variants are also treated with replacement doses of the deficient hormone.

THE ADRENAL MEDULLA

Anatomy. The adrenal medulla is embedded in the centre of the adrenal cortex. It is quite small, making up only about 10 percent of the total adrenal weight. It is composed of chromaffin cells, so called because the granules within the cells darken after exposure to chromium salts. Chromaffin cells have migrated from the embryonic neural crest and represent specialized neural tissue. Indeed, the adrenal medulla forms an integral part of the sympathetic nervous system, a major subdivision of the autonomic nervous system (see NERVES AND NERVOUS SYSTEMS: *The autonomic nervous system*), and the combined activities have been referred to as the sympathoadrenal system.

Medullary hormones

Included among the medullary hormones, the catecholamines, are dopamine, norepinephrine, and epinephrine, all of which are synthesized in the brain and sympathetic nerve endings. The adrenal medulla differs from most other endocrine glands in that the major stimulus for the release of the catecholamines is by stimulating sympathetic nerve endings to release acetylcholine (ACh), an important neurotransmitter of the peripheral nervous system (nerves and ganglia located outside the central nervous system, or the brain and spinal cord). When stimulated, the medullary cell ejects the chromaffin granules from the cytoplasm into the bloodstream, a process known as exocytosis. Thus, the adrenal medulla is a neurohemal organ.

Synthesis of catecholamines

Catecholamines. The catecholamines are synthesized from the amino acid L-tyrosine. Serial changes in chemical structure are catalyzed by enzymes, leading to the following synthetic sequence: L-tyrosine → L-dopa (dihydroxyphenylalanine) → dopamine → L-norepinephrine (noradrenaline) → L-epinephrine (adrenaline). The close proximity of the adrenal cortex to the adrenal medulla is not accidental. The enzyme that mediates the transformation of L-norepinephrine to L-epinephrine is formed only in the presence of high local concentrations of glucocorticoids from the adjacent cortex; chromaffin cells in tissues outside the adrenal cortex are incapable of synthesizing epinephrine.

L-dopa is well known for its role in the treatment of parkinsonism, but its biological importance lies in the fact that it is a precursor of dopamine, a neurotransmitter widely distributed in the central nervous system, including the basal ganglia of the brain (groups of nuclei within the cerebral hemispheres that collectively control muscle tone, inhibit movement, and control tremor). It is a deficiency of dopamine in these ganglia that leads to parkinsonism, a deficiency that is at least partially repaired by the administration of L-dopa. Under ordinary circumstances, far more epinephrine than norepinephrine is released from the adrenal medulla; in the catecholamine neurotransmitting function throughout the body, norepinephrine is far more widespread. It is likely that the full complement of hormones secreted by the adrenal medulla is not yet completely known. There is strong evidence to indicate, for example, that enkephalins (neurotransmitters with opiate-like effects) are contained within chromaffin granules and are secreted into the general circulation.

In physiological terms, a major action of the hormones of the adrenal medulla conjoined with the sympathetic nervous system is to initiate a rapid, generalized bodily response described by Walter Cannon as "fight or flight." This response may be triggered by a fall in blood pressure, pain (including burns), or abrupt emotional upheavals. An injection of epinephrine, in fact, closely mimics the symptoms of an anxiety attack (sweating, tremor, greatly increased heart rate). Metabolic changes also stimulate catecholamine secretions as evidenced by the rapid rise in plasma epinephrine levels when an individual becomes hypoglycemic (has a greatly decreased glucose level). Thus, much of what is called a hypoglycemic reaction is the result of a large epinephrine discharge.

Action of catecholamines

The action of catecholamines on the body's organs and tissues is widespread and complex. There actions, however, are rarely isolated; they usually occur in concert with other neural or hormonal responses. Furthermore, tissue responses depend on the fact that there are two major types of adrenergic receptors on the surface of target organs and tissues: alpha-adrenergic and beta-adrenergic receptors, or alpha receptors and beta receptors, respectively (see NERVES AND NERVOUS SYSTEMS: *Biodynamics of the vertebrate nervous system*). Both contain a number of subtypes so that receptor responses to the catecholamines have some degree of specificity and coordination. In general, the alpha-adrenergic receptors constrict blood vessels and the uterus, relax the intestine, and dilate the pupils. Beta receptors stimulate the heart, dilate the bronchi and blood vessels, and relax the uterus and intestines. It should be noted that there also are specific receptors to dopamine.

The effects of catecholamines on the heart result mainly from their association with beta receptors. When catecholamines bind to these receptors in the surface membranes of heart cells, pulse rate and strength of heart muscle contraction are increased so that the amount of blood moved through the heart per minute (cardiac output) increases. This sequence of events increases the body's requirement for oxygen and raises blood pressure, a consequence of greater blood flow through the heart. Drugs, such as propranolol, that block the activation of these beta receptors (beta blockers) are often used for the treatment of high blood pressure and cardiac pain (angina pectoris). Conversely, since activation of beta receptors results in bronchial dilation (expansion of the air passages in the lung) because of the heightened need for oxygen, propranolol is contraindicated in the treatment of asthma; it would worsen the bronchial constriction that already exists in the condition.

Catecholamines also play key roles in the generation of body heat (thermogenesis). Oxygen is consumed in metabolic processes in the body that produce heat. When catecholamines stimulate beta receptors and increase the overall level of oxygen in the body, more oxygen is consumed, and more heat is produced. Catecholamines also increase available body fuels such as glucose and free fatty acids. They stimulate the breakdown of glycogen, which is stored in the liver and muscle, to glucose (glycogenolysis) and the breakdown of triglycerides, the stored form of fat, to free fatty acids (lipolysis). Finally, the catecholamines are regulatory agents in hormone secretion; they serve as neurotransmitters modulating the secretion of releasing hormones in the hypothalamus, and they stimulate the release of glucagon and somatostatin and inhibit the release of insulin from the islets of Langerhans of the pancreas.

Role as neurotransmitters

All catecholamine effects on hormonal secretion are stimulatory and affect the thyroid and parathyroid, the gonads (ovary and testis), and the placenta. There is evidence, however, that stimulation of dopaminergic receptors blocks the secretion of aldosterone from the adrenal cortex. Excessive secretion or ingestion of the thyroid hormones increases the number of beta receptors so that many of the clinical consequences of the hyperthyroid state can be suppressed by using beta blockers.

Adrenomedullary dysfunction. Isolated loss of the medulla of both adrenals does not occur; such destruction is always accompanied by impairment of the function of the

cortex of both adrenals. Any effects that can be attributed to the loss of the medulla are overshadowed by the predominating signs of Addison's disease.

Tumours of the adrenomedullary chromaffin cells, called pheochromocytomas, do occur and may produce striking, largely predictable signs and symptoms that are exaggerations of the physiological actions of the catecholamines. Pheochromocytomas are tumours of the chromaffin cell, usually benign but occasionally malignant. Commonly unilateral, these tumours may be present in both adrenals when they appear in the hereditary form of multiple endocrine neoplasia. Extra-adrenal tumours of these chromaffin cells have been found in multiple locations, extending from the patient's neck to the urinary bladder, most often in a collection of cells known as the organ of Zuckerkandl. While the normal adrenal medulla secretes mostly epinephrine, pheochromocytomas predominately secrete norepinephrine.

High blood pressure is an invariable finding in adrenomedullary hyperfunction. It may be constant, and it may be difficult to distinguish from the common forms of hypertension. In some instances, however, there is a sudden increase in norepinephrine secretion, provoking the sudden explosive onset of its vasopressor actions, such as a severe headache, excessive sweating, palpitation of the heart, ashen pallor, tremor, and anxiety. These attacks may end abruptly and the patient may appear to be normal following the attack. They may last from minutes to hours and may occur at intervals ranging from, for example, once a month to several per day. In persons in whom tumours secrete an appreciable amount of epinephrine, anxiety may be more marked and the patient may lose weight, be feverish, and show evidence of diabetes mellitus.

Treatment

Excess secretion of either norepinephrine or epinephrine by such tumours may be treated therapeutically or in preparation for surgery by using alpha- or beta-receptor antagonists (drugs that compete with epinephrine and norepinephrine for receptor sites on target organs but do not elicit a response once bound; in essence they tie up many of the potential binding sites of these overly secreted catecholamines). Surgical removal of the isolated tumour remains the favoured treatment. When malignant pheochromocytomas have spread to other organs, however, antagonist drugs may be continued indefinitely.

THE OVARY

Anatomy. The ovaries are multipurpose organs. They harbour, nurture, and guide the development of the egg so that when it is extruded from the ovary (ovulation) it has been prepared for its migration down the fallopian tube, its penetration by sperm, and its eventual implantation in the wall of the uterus. Additionally, the ovary is a sophisticated endocrine structure. It secretes hormones essential for the onset of menstruation (menarche) and its cyclical perpetuation. At the same time, the ovary produces profound alterations in body physique that transforms a prepubertal girl into a mature woman.

The mature ovary is a roughly bean-shaped structure weighing about 14 grams. It, like the adrenal gland, consists of an outer cortex and a central medulla with the addition of an inner hilus (depression or pit) that serves as the point of entry and exit of blood vessels and nerves. The ovaries are located in the pelvis, attached to a structure called the broad ligament (see REPRODUCTION AND REPRODUCTIVE SYSTEMS: *The human reproductive system*).

Follicle maturation

Immature follicles (primordial follicles) embedded in fibrous tissue (stroma) enlarge as the follicle matures and moves through the cortex toward the outer surface of the ovary. The cells lining the follicle multiply and become layered into a zona granulosa. Along with this change the stromal cells immediately surrounding the follicle arrange themselves concentrically to form a theca (an enclosing sheath). This egg-containing mature structure is known as a Graafian follicle. Both granuloma cells and thecal cells secrete steroid hormones known as estrogens. The follicular fluid bathing the ovum is an extraordinarily complex liquid containing not only high concentrations of estrogens but also other steroids (progestogens and androgens), pituitary hormones (FSH, LH, prolactin, oxytocin, and vasopressins), and numerous enzymes and bioactive proteins.

During the maturation (follicular) phase of the menstrual cycle, follicles continue to enlarge until one (or, rarely, two) follicles rupture at the ovarian surface. The egg is extruded and promptly enters the fallopian tube to begin its journey to the uterus. The supportive role of the follicle does not end with the discharge of the egg. Thecal cells penetrate the emptied follicle and, together with persisting but modified granulosa cells, fill the follicle, now called a corpus luteum, which is the source of serum progesterone during the postovulatory (progestational or luteal) phase of the menstrual cycle. With menstruation, the corpus luteum becomes scarred and contracted (atretic), remaining as a corpus albicans. In the event that the extruded egg is fertilized and pregnancy ensues, the corpus luteum persists and continues to secrete increasing amounts of progesterone during the first trimester. As might be expected, these changes are controlled by secretions from the hypothalamus and the anterior pituitary gland.

Regulation of hormone secretion. Before the onset of puberty the ovaries are quiescent, and the stroma of the cortex and medulla are studded with multiple primordial follicles. Puberty is heralded by subtle but far-reaching changes. Some undefined event stimulates the secretion of luteinizing hormone-releasing hormone (GnRH) from the hypothalamus, and GnRH secretion becomes pulsatile. Animal studies support the notion that puberty is precipitated by a reduction in the secretion of melatonin, a hormone of the pineal gland. There is, however, no evidence that melatonin has a role in the onset of puberty in humans.

The onset of puberty

Secretion of GnRH activates gonadotrophs from the anterior pituitary, resulting in enhanced secretion of both follicle-stimulating hormone (FSH) and luteinizing hormone (LH). The secretion of these hormones, particularly LH, is much enhanced shortly after the onset of sleep; increased nocturnal secretion of LH is the earliest change detectable in the pubertal child. It appears that GnRH secretion is inhibited by neurons that secrete dopamine and is stimulated by noradrenergic neurons (involved with norepinephrine). Endogenous opiates, especially beta-endorphin and dynorphin, also play important roles in regulating the frequency and strength of GnRH secretion.

The increased secretion of estrogens from the ovaries, stimulated by LH secretion coupled with maturing Graafian follicles (resulting from the increased FSH secretion) leads to menarche. Before long, the cyclic activity characteristic of the normal female hypothalamus appears (Figure 14B). Immediately following the cessation of menstruation, the sequence begins with a gradual rise in the blood level of estradiol (the most potent of the estrogens), paralleled by a slow rise in serum LH. An inconspicuous rise in androgens also occurs while progesterone and its precursor, 17-hydroxyprogesterone, remain suppressed. Finally, the rising estradiol level trips off a mid-cycle surge of LH and FSH (an example of a positive feedback mechanism). The abrupt rise in gonadotropins precipitate ovulation, ending the follicular phase. With the formation of the corpus luteum, estrogen levels fall but not back to baseline, while the levels of 17-hydroxyprogesterone and progesterone are much elevated. At the end of the luteal phase all hormonal levels return to baseline, and the withdrawal of the estrogens precipitates the next menstrual period. The normal menstrual cycle is 28 days long although it varies considerably from one woman to another and occasionally in the same woman, with irregularities occurring most frequently shortly after puberty or before the menopause.

The premenstrual fall in levels of estrogen and progestins occurs because of a degeneration and loss of function of the corpus luteum (luteolysis) that results from a faltering of LH pulses from the pituitary. The endometrium, which had become increasingly thickened and vascular, undergoes a constriction of small arteries. Cutting off oxygen and nutrient supplies to the endometrial lining leads to cell death and the subsequent sloughing and bleeding characteristic of menstruation. It should be noted that the basal body temperature, which fluctuates only mildly during the follicular phase, shows a rather abrupt progressive rise

Luteolysis

after ovulation, paralleling the increase in progesterone (Figure 14A). This thermogenic action results from the effect of the elevated progesterone levels on temperature-regulating centres in the base of the brain. (The structural and functional changes that occur in the fallopian tubes [oviducts], lining of the uterus [endometrium], distal opening to the uterus [cervix], and vagina and that accompany the endocrinologic fluctuations are discussed in the article REPRODUCTION AND REPRODUCTIVE SYSTEMS: *The human reproductive system*. The extension and accentuation of these changes, which occur in the event of pregnancy, are also discussed there.)

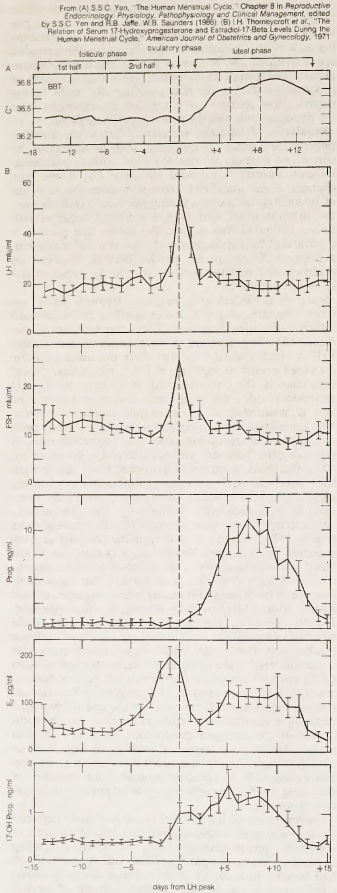


Figure 14: *Normal cyclical changes that occur during normal ovulatory menstrual cycle.*
(A) Changes in basal metabolic temperatures (BBT). (B) Normal levels of luteinizing hormone (LH), follicle-stimulating hormone (FSH), progesterone (Prog.), estradiol (E_2), and 17-OH progesterone (17-OH Prog.).

Hormones. As is the case in the adrenal cortex, the parent sterol from which all ovarian steroid hormones are formed is cholesterol. Both estrogens and progestogens are synthesized from a common precursor, pregnenolone, itself formed from cholesterol. These chemical sequences also include dehydroepiandrosterone, androstenedione, and testosterone, all of which are steroids that are primarily androgens (male sex hormones).

Synthesis of ovarian hormones

Once secreted into the blood, estrogens share with androgens, particularly testosterone, a binding globulin (testosterone-estradiol-binding globulin, TeBG), which transports them to target tissues. At this site, the estrogens easily penetrate the cell surface and are bound to an intracellular binding protein. It is in this form that they are transported to the cell nucleus, where they modulate protein synthesis by influencing the formation of DNA.

Estradiol, the most potent of the three major estrogens, is formed by both granulosa and thecal cells, perhaps acting together. Estrone can be formed from estradiol, but its major precursor is androstenedione. Estriol is formed from both estrone and estradiol and is the weakest of the estrogens. Indeed, in some circumstances estriol appears to have anti-estrogen effects; that is, it may bind to tissue estrogen receptors without setting in train estrogen effects and, while doing so, block the receptor from access to more potent estrogens such as estradiol. It has been suggested that it protects against the development of breast cancer in women. Catechol estrogens are metabolic products that also have anti-estrogen effects.

Formation of progesterones

The progesterones (progestins) are formed by the corpus luteum. Progesterone is also produced by the adrenal cortex, but the rise that occurs in its serum level during the luteal phase stems from ovarian secretion. The hormone 17-hydroxyprogesterone is secreted by thecal cells and accounts for most of the hormone found in the blood; again, the adrenal cortex may secrete a lesser amount at a constant rate.

Among the many nonsteroidal substances secreted into the follicular fluid is a substance called inhibin (folliculostatin), which is secreted by granulosa cells (and by Sertoli cells in the male). The primary action of inhibin is to inhibit the secretion of pituitary FSH. Since the major action of FSH is to stimulate the formation and function of granulosa cells, the relationship between inhibin and pituitary FSH represents a classical negative feedback servomechanism. Relaxin, a polypeptide hormone produced by the corpus luteum, induces a relaxation of the pubic ligaments connecting the two halves of the pelvis, an action that mitigates the discomfort of a woman in labour and eases the passage of the child. Finally, the ovary contains both oxytocin and vasopressin in high concentration, which serve a paracrine function. Oxytocin may assist in the expulsion of the egg from the ovary and may also mediate the process of luteolysis (break up of the corpus luteum). Vasopressin constricts local blood vessels after the egg is extruded.

Functions of ovarian hormones

Ovarian hormones have multiple functions. Pulsatile secretion of LH occurs well before the onset of the first menses (menarche) so that the rate of estrogen secretion also increases progressively. This results in the progressive development of breasts (thelarche) and the appearance of pubic hair and culminates in the menarche. Estrogens, including those contained in oral contraceptives, also exert ongoing generalized effects in the adult female. They mildly impair the body's ability to metabolize glucose, and they tend to increase the level of fats (triglycerides) in the blood. These effects are easily obviated by other endocrine adjustments in the normal woman, but they have an impact when these compensatory mechanisms are impaired. Estrogens increase the serum concentration of a large number of binding proteins that transport other materials; these include binding proteins for cortisol, thyroxine, iron, and copper, as well as those that bind estrogens and testosterone (TeBG). Finally, estrogens tend to increase the concentration of sodium, and therefore the degree of water retention, again particularly in susceptible women.

Diseases and disorders. *Precocious puberty.* In a setting such as the ovary, in which a complex train of interlocking hormonal activities must occur in proper sequence, it is not surprising that there are a number of abnormalities in function. Among them is precocious puberty, defined as the onset of menstruation before the age of nine years. In true precocious puberty, which may occur as early as the age of two years, ovulation takes place, and the child must be protected from the threat of pregnancy. The cause of this disorder is unknown, and affected girls are otherwise normal.

Nonetheless, treatment is important for proper psychological and social development. Synthetic steroids that inhibit the secretion of gonadotropins from the pituitary have been used successfully. They lead to the regression of breast size, the suppression of menstruation, and the prevention of aberrations of height (a pubertal growth spurt that takes place too early, followed ultimately by short stature in the adult). This form of treatment is being superseded by the use of synthetic derivatives of hypothalamic GnRH. These derivatives are long-acting and block pituitary receptors, both by occupying receptor sites and by preventing the pulsatile stimulation by the naturally occurring GnRH.

Pseudo-precocious puberty

Pseudoprecocious puberty occurs from tumours that secrete GnRH or from tumours that secrete the gonadotropins themselves. Although these patients show breast development, the appearance of pubic hair, and menstrual bleeding, they do not ovulate and they are infertile. Treatment is directed against the tumour that is secreting the hormones.

Menstrual disorders. In the adult female who has matured normally, any of a number of menstrual dysfunctions can appear, most of which lead to infertility. Indeed, a common disorder that occurs most often during adolescence or around the menopause is dysfunctional uterine bleeding. Menstrual bleeding occurs at irregular intervals and ovulation is absent. It results from a sluggish LH response to rising estrogen levels in girls and a suboptimal estrogen rise in aging women. Treatment may be with progestins or an estrogen-progestin combination. A second disorder that is being diagnosed with increasing frequency is hyperprolactinemia (see above *The anterior pituitary gland: Prolactin*), but not always associated with a disappearance of menses (amenorrhea) and the spontaneous secretion of breast milk (galactorrhea).

A rare, but intriguing, aberration is false pregnancy (pseudocyesis). A woman, wanting to be pregnant, generates impulses from the cerebral cortex that stimulate the hypothalamus, resulting in an increase in the secretion of LH and prolactin. Changes typical of a first trimester pregnancy then appear. These changes regress promptly when the patient is made aware that she is not pregnant. A mild form of this disorder occurs in patients in whom the corpus luteum persists for longer than the normal 14 days. This persistent corpus luteum syndrome may lead to a prolonged period of amenorrhea.

Anorexia nervosa

A more threatening form of amenorrhea occurs in patients with anorexia nervosa, in which voluntary food restriction is stringent, and in those with bulimia, in which periodic eating binges are followed by self-induced vomiting. The severely affected patient, by mechanisms not well understood, physically regresses to a prepubertal state; amenorrhea and suppression of gonadotropin secretion occur. This regression is associated with a reduction in total fat stores below a critical weight and is almost always reversed by weight gain. These changes may be related to the ability of fat tissue to metabolize estrogens from estrone through the most potent steroid, estradiol, to the least potent, estriol.

The treatment of patients with anorexia nervosa varies with the severity of the malnutrition. Intravenous infusion of nutrients (parenteral alimentation) is used in those whose illness has become life-threatening. In those affected less severely, the treatment is psychological, and the best results are obtained when the patient's family participates along with the patient. A less threatening variant is the amenorrhea of the ballet dancer or marathon runner whose single-minded pursuit of excellence through strenuous physical activity leads to a reduction of fat mass below the critical level. Again, if the individual is compliant, effective treatment consists simply of reducing the amount of strenuous physical activity.

The psychological influence on hypothalamic function is also manifest in a far less severe disorder, psychogenic amenorrhea. Individuals so afflicted respond to psychological stress by reducing gonadotropic secretion; normal menses return when the stress is relieved.

Some young adult women who are in otherwise good health, suffer at the time of menstruation from pelvic cramps (dysmenorrhea), headache, nausea, vomiting, weakness, and dizziness long thought to be psychological in origin. It has become clear that the symptoms are not psychogenic but, rather, are due to an increased secretion of prostaglandins from the uterus. Prostaglandins increase the strength of uterine contractions and cause widespread constriction of blood vessels. The patient's symptoms are completely or partially relieved by taking drugs that inhibit the synthesis of prostaglandins (*e.g.,* ibuprofen, or indomethacin).

Premenstrual syndrome

Another constellation of symptoms that has generated debate is premenstrual syndrome (PMS). Perhaps one in 10 women with normal cycles becomes aware of breast tenderness, weight gain with bloating of the abdomen and swelling of the feet, increased irritability with mental depression, and fatigue. The symptoms appear seven to 10 days before the onset of menstruation. In extreme instances, episodes of violence or other forms of psychotic behaviour follow. Evidence suggests that PMS is due to an increased secretion of endogenous opiates, followed by a rather abrupt withdrawal of these mood-altering hormones. A number of drugs, including GnRH analogues, narcotic antagonists, and clonidine, a drug that stimulates alpha-andrenergic receptors, have been used in treatment.

In addition to the functional (secondary) causes of amenorrhea described above, there are abnormalities in which menstruation is never initiated, the primary amenorrheas. These disorders may reflect serious problems in growth and development (see below *Growth and development: Disorders of growth*). Only a more benign aberration is considered here, that of delayed puberty and adolescence. It is not rare that an otherwise normal girl not have the onset of puberty until after age 13, with delays extending as long as age 18. This delay in adolescence is a benign variant of the normal pubertal process. It is important to reassure the patient and her family and to deal with the psychological problems that this lag in development may produce.

Physical effects of menopause

The menopause. The menopause occurs in women between the ages of 45 and 55 years, with the five-year interval between 45 and 50 being the most frequent time of onset. During the menopause the ovary's eggs and their nurturing Graafian follicles are depleted, and the ovary shrinks and becomes wrinkled; it contains many atretic follicles, and the stroma cells become much increased. Such ovaries cannot synthesize sufficient estrogen to sustain the premenopausal relationships of the hypothalamic-pituitary axis. Thus, as the serum estrogen levels fall, pituitary secretion is less inhibited, and there is a progressive increase in the levels of pituitary gonadotropins. The senescent (aging) ovary, however, is no longer capable of responding to pituitary hormones.

As a result of progressive estrogen deficiency, the uterus and breasts decrease in size, the vagina becomes dry, and sexual intercourse often becomes painful (dyspareunia). In about three-fourths of all females there occurs some degree of increased irritability along with "hot flashes," characterized by a flushing of the skin, profuse sweating, and a feeling of warmth. These episodes are a frequent source of embarrassment during the day and a cause of insomnia at night. While the mechanism is not clearly understood, it has been shown that there is an abrupt rise in pituitary LH secretion simultaneous with a rise in skin temperature. Probably both of these parallel changes are due to simultaneous stimulation of temperature-regulating centres and GnRH production at the base of the brain. There is a minority of women who suffer no menopausal symptoms. It is thought that they are able to convert

enough steroid precursors into estrogens, particularly in fat tissue, to avoid the abrupt fall in estrogen levels that are the rule. An important consequence of the menopause in caucasian women is osteoporosis (see above *The parathyroid glands: Metabolic bone disease*).

Premature ovarian failure

When menses ceases before age 40, the patient is said to have premature ovarian failure. Some of these patients may be afflicted with a genetic disorder. In others, premature failure may be generated by ovarian autoantibodies. Others suffer a loss of ovarian receptors (the resistant ovary syndrome) for unknown reasons.

Administration of estrogens suppresses menopausal symptoms in most women, but estrogen treatment increases the risk of carcinoma of the lining of the uterus and perhaps of the breast as well. Some physicians recommend a combination of estrogens and progestins to simulate a normal menstrual cycle. Some investigators have recommended that all menopausal women be given hormonal replacement indefinitely, but others are concerned that the prophylactic administration of these hormonal agents to the entire postmenopausal population may be costly in terms of benefits as compared to risks. They believe that the administration of hormones should be reserved only for those who have distressing symptoms or who are likely to develop osteoporosis.

Functional androgen excess. Androgens are integrated into the normal endocrinologic pattern of functioning in the adult woman. The two major androgens secreted by the ovaries are androstenedione and testosterone; dehydroepiandrosterone (DHEA) and DHEA-sulfate (DHEAS) are contributed by the adrenal cortex. Other tissues, including skin, fat, muscle, and brain, are capable of converting precursor steroids locally to active hormones, thus permitting the accumulation of high concentrations of steroids in key local areas without having a generalized effect throughout the body.

Local activation of steroid hormones

In view of the numerous sites of androgen production, it is not surprising that there are multiple causes for syndromes of androgen excess. Some, such as Cushing's syndrome, congenital adrenal hyperplasia, and androgen-producing adrenal tumours, have been discussed previously (see above *The adrenal cortex: Congenital adrenal hyperplasia*), where the important distinction between hirsutism and virilization is made. Tumours (including cancers) of granulosa and thecal cells of the ovary usually overproduce both estrogens and androgens and may result in all of the features of androgen excess.

While it is important to rule out these serious illnesses, they are relatively rare. Hirsutism is common, however, occurring most often as part of the syndrome of polycystic ovaries (PCO). Since any of a number of androgens may be secreted in excess in this syndrome, it probably has more than one cause; and the androgens arise either from the adrenals or the ovaries. The ovaries become enlarged with a thickened capsule and contain many atretic follicles. Typically, the patient has hirsutism, amenorrhea, infertility, acne, and obesity. The obesity leads to an excess of estrogens from conversion of androgens in peripheral tissues, resulting in impaired secretion of gonadotropins and a consequent suppression of ovulation, with or without amenorrhea.

Treatment involves suppressing excess adrenal androgen production by using synthetic glucocorticoids such as prednisone, by suppressing the actions of the ovary using oral contraceptives, or by blocking the androgenic receptors in tissues with antagonistic drugs such as spironolactone. Effective treatment restores normal menstrual activity and fertility, and although it does not reverse the hirsutism in most instances, further progression is arrested.

THE TESTIS

Anatomy. The testes, or testicles, are the male gonads. They contain germ cells that differentiate into mature spermatozoa, supporting cells called Sertoli cells, and testosterone-producing cells called the Leydig cells. The germ cells migrate to the fetal testes from the embryonic yolk sac. The Sertoli cells are analogous to the granulosa cells in the ovary, and the Leydig (interstitial) cells are analogous to the stromal cells of the ovary.

The embryonic differentiation of the primitive, indifferent gonad into either the testes or ovaries forms a fascinating chapter in fetal development (see below *Growth and development*). Testosterone and its potent derivative, dihydrotestosterone, play key roles in the formation of male genitalia in the fetus in the first trimester of pregnancy. During the first four weeks after birth, they sensitize the genitalia to respond appropriately to androgens when puberty begins. The testes are formed in the abdominal cavity and descend into the scrotum during the seventh month of pregnancy. Stimulation of testicular descent is provided by androgens, along with a protein hormone called Müllerian-inhibiting substance. It is not uncommon in normal males for the testes to be incompletely descended and easily retracted into the abdomen, but this condition usually corrects itself by the age of three months.

Masculinization of the fetus

The adult testis consists largely of a series of tubules with a central cavity. Sperm cells are continuously maturing as they move from the outer edge of the tubule into the central lumen; the most primitive forms, called spermatogonia, differentiate first into spermatocytes and then spermatids. They eventually mature into spermatozoa and are released into the lumen. Spermatozoa travel through the tubular network to be stored in seminal vesicles and, finally, to be ejaculated with the semen. Interspersed among the seminiferous tubules are Sertoli cells, and in the area between tubules (interstitium) are located the hormone-secreting Leydig cells.

Regulation of hormone secretion. Androgen levels in the circulation are regulated by the classical hypothalamic-pituitary-target gland axis (Figure 3). The secretion of pituitary LH (sometimes referred to in the male as interstitial cell stimulating hormone, or ICSH) is secreted following stimulation by gonadotropin-releasing hormone (GnRH) from the hypothalamus. Luteinizing hormone stimulates the Leydig cells to secrete testosterone. When testosterone levels rise above normal, GnRH and LH secretion are inhibited. In the normal course of events, therefore, testosterone levels remain within normal bounds.

The hypothalamic component of this axis comes into play when it is appropriate to override the usual constraints. It has been shown in primates, for example, that serum testosterone levels rise when males are placed in proximity to receptive females, but the level falls when these same males are caged with unreceptive, hostile males to whom they are strangers. It is thought by some that the reduction in serum testosterone levels in such an alien environment is accompanied by a decrease in aggressive behaviour, which, literally, may have survival value. A relation between androgen levels and aggressive behaviour in humans remains uncertain; complex social and interpersonal factors make interpretation difficult.

Transport of testosterone

Like other steroid hormones, testosterone is transported in the plasma bound to a testosterone-binding globulin (TeBG) and to albumin. Only about 2 percent of testosterone is transported unbound in the plasma. Free testosterone is in equilibrium with that which is bound so that when the free steroid enters the cell some bound testosterone is freed simultaneously.

Hormones. Testosterone serves as a circulating prohormone for an important steroidal metabolite, dihydrotestosterone, that performs most of the androgenic functions in the body. Testosterone may also be converted into the potent estrogen estradiol in tissues, particularly adipose tissue. Furthermore, testosterone is interconvertible with androstenedione, which, again in adipose tissue, may be converted to the estrogen estrone.

Testosterone has two major actions: it serves as the feedback inhibitor of GnRH secretion from the hypothalamus and LH secretion from the pituitary, and it directs the development of embryonic Wolffian ducts into the formation of seminiferous tubules. Dihydrotestosterone is responsible for ongoing sperm maturation (spermatogenesis), for the virilization of the embryonic genitalia, and for sexual maturation at puberty. In addition, androgens are powerful anabolic hormones; that is, they enhance the growth of body tissues, particularly muscle.

Normal spermatogenesis requires the secretion of LH and FSH. Luteinizing hormone stimulates testosterone se-

cretion from Leydig cells in the stroma of the testis; the testosterone is converted to dihydrotestosterone, and it must be present locally in high concentration for normal generation of sperm to proceed. Follicle-stimulating hormone acts directly on the seminiferous tubules to stimulate the normal maturation of sperm. Finally, as indicated previously, androgens stimulate Sertoli cells to secrete inhibin. When released into the blood, inhibin dampens pituitary FSH secretion, an additional component of the feedback control mechanism.

Diseases and disorders. *Precocious and delayed puberty.* Male children also can undergo true precocious puberty or the various forms of pseudoprecocious puberty. In addition, there is a poorly understood form of sexual precocity that is a familial (autosomal dominant) disorder in which precocious puberty appears in males in the absence of any increased pituitary gonadotropin secretion and in the absence of any hormone-secreting tumour. The reasons for this inherent premature overactivity of the testes are unknown. It has been suggested that it be called familial testotoxicosis.

Familial precocious puberty

The young child develops pubic hair, a pigmented scrotum, an enlarged penis, and increased muscle development. Since in the affected male child, unlike the female with true precocious puberty as described above, the hypothalamus and pituitary are not activated, treatment with GnRH analogues is not effective. Instead, these patients are treated with an inhibitor of testosterone synthesis called ketoconazole. Severe disease of the testes can prevent completely, or block partially, the onset of puberty.

Hypogonadism. In addition to the functional changes akin to those previously described in females and leading to delayed puberty and adolescence, there are organic diseases that lead to permanent gonadal deficiency. Aside from the various forms of disease and injury, including surgery, that lead to panhypopituitarism, the most common form of gonadotropin deficiency is due to a defect in the hypothalamus that results in an inability to synthesize and secrete GnRH. Persons with this defect (Kallmann's syndrome) may be born with other malformations, including a much undersized penis (microphallus), and there is often an associated loss of smell (anosmia). They do not undergo puberty unless treated. That the defect lies in the hypothalamus is shown by the fact that when these individuals are treated with GnRH, serum gonadotropin levels increase. Conventional treatment of this disorder has been with injections of testosterone, but nasal insufflation of GnRH has been successful.

There are a number of other causes for gonadotropin deficiency. Various tumours in the area of the hypothalamus and pituitary as well as a number of rare disorders, such as the Prader-Labhart-Willi syndrome, may produce hypogonadotropic hypogonadism, in the latter instance due to a chromosomal defect.

Factors causing hypogonadism

In the adult male hypogonadism can occur as a consequence of hypothalamic or pituitary deficiencies (see above *The hypothalamus: Gonadotropin-releasing hormone*). In addition, gonadotropin secretion may be suppressed when hyperprolactinemia occurs (see above *The anterior pituitary: Prolactin*). The testes are susceptible to acquired diseases as well, the most common being mumps orchitis, usually affecting only one testis (unilateral), but when both testes are infected full-blown hypogonadism and infertility may result. Physical trauma, X-ray therapy, and a number of drugs, including commonly used chemotherapeutic agents for the treatment of cancer, can temporarily or permanently impair testosterone synthesis. Alcoholics who sustain severe liver damage are often estrogenized, but alcoholism is associated with a direct inhibition of testosterone synthesis as well. Finally, gonadal failure is commonly associated with a number of chronic illnesses, particularly kidney disease and sickle-cell anemia.

Symptoms of testosterone deficiency

The symptoms of testosterone deficiency in the adult male include the cessation of hair loss. (Normal testosterone levels are necessary for the usual pattern baldness, which occurs frequently in mature men; the converse is not true, however, and most men who retain a full head of hair also maintain normal circulating androgen levels.) The skin of the hypogonadal male is smooth, with a rather fine wrinkling, particularly in front of the ears and around the mouth. Hair in the pubic area and in the beard becomes sparse. There may be some breast enlargement (gynecomastia), and the hips may become broad and assume a female configuration (gynecoid habitus). The testes become smaller than normal, and they may be insensitive to pain. Affected individuals complain of weakness, usually lose interest in sexual activity, and are unable to achieve an erection or to ejaculate.

Treatment of androgen deficiency caused either by a hypothalamic-pituitary axis defect or by a gonadal defect includes the administration of testosterone, usually by intramuscular injection. Many of the symptoms are entirely reversible. Testicular size, however, may decrease even further because of the inhibition of FSH secretion resulting from the administration of testosterone.

Hypergonadism. Testicular tumours occur both in children and in adults. Tumours may appear in both testes, and the risk is much increased in those who have undescended testes (cryptorchidism). By far the most common tumours are those of germ cells (seminomas). Previously almost uniformly fatal, testicular tumours are now treated through surgery and chemotherapy, and the survival rates of patients harbouring these tumours have risen dramatically. Tumours of the Leydig cells are quite rare and are almost always benign. Nonetheless, they secrete large quantities of testosterone, precipitating a pseudopuberty in the prepubertal boys and hypergonadism in adult males. The hypergonadal male may lose head hair while showing increased abnormal hairiness in other areas of the body. Acne often reappears, and there may be muscular enlargement due to overgrowth of cells. Because large amounts of the excess testosterone are metabolized to estrogens, patients may develop enlarged breasts.

Testicular tumours

GROWTH AND DEVELOPMENT

The processes of growth and development are usually accepted as facts of everyday life; however, when one considers the powerful forces at work and the many harmoniously intermingled regulators that harness them, the emergence of a mature adult human being is a source of wonder. The carefully monitored conversion of a crude mixture of nutrients, often ill-balanced, into growing body tissues is integral to the purview of the endocrine system, although the nervous and immune systems play important roles as well.

From the 10th to the 20th week of pregnancy, the fetus grows at a rate of 52 inches (132 centimetres) per year. This phenomenal growth rate tapers rapidly as birth approaches. Weight at birth is an important marker. Low birth weight is not surprising in infants coming from families whose histories include low birth weight, but it may also be an indication of premature birth or of poor intrauterine nourishment from a mother living in poverty or with poor hygiene. Growth during infancy remains rapid and then progresses at a slower but steady rate until the onset of puberty, when there is a striking acceleration. The pubertal growth spurt lasts about two years, and it is accompanied by the appearance of secondary sexual characteristics. With puberty, there ensues an increase in nocturnal secretion of growth hormone.

Patterns of growth

Endocrine influences. Accurate estimates of bone age are made by examining radiographs (a film record of a structure using X rays) of the hands and wrists of large numbers of normal children. In children with endocrine disorders, bone age may not correlate closely with chronological age; bone age is retarded in growth hormone-deficient children and increases in children with growth hormone-producing tumours. Hyperthyroidism, even when it occurs in the developing embryo, is associated with an advanced bone age, while the opposite is true with thyroid deficiency. Children with Cushing's syndrome not only have osteoporosis but retarded bone age as well. An excess both of androgens and of estrogens is associated with a relatively advanced bone age, while a partial androgen deficiency leads to an increase in prepubertal growth of the extremities, resulting in adults with long arms and long legs attached to a short trunk (eunuchoid habitus).

Insulin is a potent growth hormone, and childhood di-

abetics are notoriously small for their ages. Indeed, like hypothyroid children, some never advance to the pubertal state unless proper insulin replacement therapy is provided.

Growth factors. When investigators began studying the effects of biologic materials on cells and tissues developed for laboratory research outside of the body, they discovered a group of peptide hormones that were distinct from any previously known hormones and were active in stimulating the growth in size and number of these cells living outside the body. This group of peptides include somatomedins, epidermal growth factor, platelet-derived growth factor, nerve growth factor, erythropoietin, lymphokines, thymosin, and transforming growth factors, all of which are discussed below.

Somatomedins. The most intensively studied of these peptide growth factors are the somatomedins, also known as insulin-like growth factors. Of these, somatomedin-C (SmC), also called insulin-like growth factor I (IGF I), along with the related insulin-like growth factor II (IGF II) have emerged as the most important biologically. These two somatomedins are distinguishable in terms of specific actions on tissues and, more precisely, different specific tissue receptors. Somatomedin-C is a peptide with an amino acid structure strongly reminiscent of the prohormone of insulin, proinsulin. It is not surprising, therefore, that both somatomedins have effects that mimic those of insulin when incubated with adipose tissue in the laboratory, but they are far less potent than insulin.

Somatomedin-C

The major action of the somatomedins is on cell growth. Indeed, many of the effects of growth hormone are mediated by way of the somatomedins. Growth hormone stimulates many tissues, particularly those of the liver, to synthesize and secrete the somatomedins. The somatomedins, in turn, stimulate both hypertrophy and hyperplasia of most tissues, including bone. In normal children, blood levels of SmC rise progressively through puberty to adolescence. Abnormally low levels of SmC can be found in individuals with growth hormone deficiency, while abnormally high levels of SmC are found in patients with acromegaly. It is likely that the major actions of the somatomedins occur at the site of their formation, where local concentrations are quite high and cell growth can be stimulated without having the somatomedins pass through the general circulation; in effect, the somatomedins and other growth factors may exert their major actions by way of paracrine and autocrine effects.

Epidermal growth factor. Epidermal growth factor (EGF), a peptide containing 53 amino acids, has been found to be identical to urogastrone, a peptide isolated from the urine of pregnant women, which blocks the secretion of gastric juices. An unlikely, but nonetheless major, site of EGF formation is the salivary gland. Epidermal growth factor stimulates many epithelial tissues to proliferate, and it has been postulated that it plays a major role in the rapid proliferation of these tissues in the fetus. In the adult, EGF formation is dependent upon and stimulated by the presence of androgens. The full clinical implications of EGF are uncertain. A study in mice revealed that when the submandibular salivary glands were removed before an adult female became pregnant, subsequent litters had a high mortality rate within the first four weeks after birth and that maternal milk production was greatly decreased.

Platelet-derived growth factor. Platelet-derived growth factor (PDGF) is a polypeptide contained in blood platelets and released during the process of blood clotting. It stimulates the proliferation of fibroblasts (cells essential for healing) at the site of a wound. It may also play a key role in the pathological process called hardening of the arteries (atherosclerosis). Platelets are attracted to and aggregate around collections of fat in the walls of blood vessels (plaques), and the release of PDGF at these sites stimulates the proliferation of cells in the vessel walls, causing them to narrow. The aggregation of platelets has been inhibited by drugs such as aspirin (see below *Prostaglandins*) in the blood vessels of laboratory animals, thus preventing the development of atherosclerosis.

Blood clotting

Nerve growth factor. Nerve growth factor (NGF) plays an important physiological role in fetal life. It stimulates the growth of nerve cells that form the sympathetic nervous system and may play a similar supporting role in normal adults. It has been incriminated in the genesis of two unusual but disabling disorders. The first, called familial dysautonomia, is a serious affliction of the sympathetic nervous system manifested by an inability to sustain blood pressure in the erect posture, along with other defects (see above *The adrenal medulla*). Persons with the disease are unable to synthesize NGF normally. Another rare disorder, intestinal ganglioneuromatosis, which is part of a hereditary endocrine disease, multiple endocrine neoplasia type II (see below *Ectopic hormone and polyglandular disorders*), is characterized by an impressive overgrowth of nerve cells in the intestinal wall thought to be the result of hypersecretion of NGF in local supporting cells.

Erythropoietin. A number of growth factors specific for bone marrow cells have been identified. Chief among these is erythropoietin, which stimulates the bone marrow to increase the production of red blood cells (erythrocytes). Erythropoietin is a rather specialized protein, a sialoprotein, containing 70 percent protein, which is synthesized in the kidney of the adult and is released into the general circulation. In this respect it is a more orthodox hormone since its mode of action is endocrine rather than paracrine or autocrine.

The secretion of erythropoietin is stimulated both by androgens and by growth hormone, but the primary stimulus for erythropoietin secretion is a lack of oxygen in the tissues. The amount of circulating erythropoietin increases greatly in individuals living at high altitude, patients with disease of the heart and lungs, and in those with erythropoietin-producing tumours of the kidney. Erythropoietin deficiency occurs in patients with severe kidney disease and treatment with erythropoietin has been found to alleviate the anemia associated with renal insufficiency.

Mode of action

There are analogous hormonal proteins that are growth factors for two types of white blood cells, both granulocytes and monocytes. These proteins have been referred to as colony-stimulating factors and macrophage growth factors, respectively.

Lymphokines. Lymphocyte production is regulated by growth factors known as lymphokines. Among the lymphokines are a group known as the interleukins. Interleukin-1 stimulates the growth of monocytes and also stimulates the production of interleukin-2, which in turn stimulates the proliferation of T cells. Interleukin-3 acts on lymphocytes at an earlier stage of differentiation (see IMMUNITY).

Thymosin and thymopoietin. The thymus gland has important functions in the immune system, but it also produces a growth factor called thymopoietin, a single-chain peptide consisting of 49 amino acids that stimulates the differentiation of primitive thymus lymphoid cells (prothymocytes) into mature T cells. Thymosin, a 28-amino-acid peptide, stimulates the growth and differentiation of thymocytes and has been reported to be helpful in the treatment of persons with inherited immunodeficiency disease (see IMMUNITY).

The thymus gland

Transforming growth factors. An important area of research has been the exploration of roles played by certain growth factors in transforming normal cells into malignant cells. Unlike normal cells under similar conditions, transformed cells grown in the laboratory in cell cultures multiply at a rapid rate even in the absence of a growth-supporting serum, and, unlike normal cells, which have a limited capacity to replicate in the laboratory, transformed cells become immortal in that they can survive in cell culture indefinitely. Presumably, the transformation permits the cells to synthesize, and be stimulated by, their own growth factors in an autocrine fashion. Transformation can take place in laboratory cultures of cells that have been infected with any of a variety of viruses. While transforming growth factors (TGF) are present in malignant cell cultures, they are present in lower concentrations in normal cells; the synthesis of TGF may be directed by specialized genes, called oncogenes.

Disorders of growth. *Sexual differentiation.* The embryological and anatomic aspects of the gonads and genitalia are detailed in the article REPRODUCTION AND

REPRODUCTIVE SYSTEMS: *The human reproductive system;* and descriptions of chromosomes and the genes they bear is described in GENETICS AND HEREDITY, THE PRINCIPLES OF: *Human genetics,* so that only a brief review is presented here. In humans, each egg contains 23 chromosomes, of which 22 are autosomes and one is a female sex chromosome (the X chromosome). Each sperm also contains 23 chromosomes: 22 autosomes and either one female sex chromosome or one male sex chromosome (the Y chromosome). An egg that has been fertilized by the penetration of a sperm has a full complement of 46 chromosomes, of which two are sex chromosomes. The genetic sex of the individual, therefore, is determined at the time of fertilization; fertilized eggs containing an XY sex chromosome complement are ordained to be males, while those containing an XX array are destined to develop as females.

The sex chromosomes

Regardless of this preordination, however, all developing embryos become feminized unless masculinizing influences come into play at key times during gestation. A testis-organizing factor assists the Y chromosome in initiating male sexual differentiation by directing the embryonic gonads, which initially are sexually undifferentiated (indeterminate), to develop as fetal testes. The X chromosome also participates in the differentiating process because two X chromosomes are necessary for the development of normal ovaries. In every embryonic life the fetus contains structures capable of developing into either male or female genitalia.

During the third fetal month, the fetal testis of the XY embryo secretes testosterone, an event that has striking consequences. The ducts that would have otherwise developed into oviducts (fallopian tubes) atrophy, while a separate set of ducts (Wolffian ducts) are stimulated to develop eventually into seminiferous tubules along with the ducts (vas deferens) connecting them to the urethra of the penis. If the fetal gonad does not secrete testosterone at the proper time, the genitalia develop in the female direction regardless of whether testes or ovaries are present. In the normal female fetus, no androgenic effects occur; the ovaries develop along with the Müllerian ducts while the Wolffian duct system deteriorates. Sexual differentiation is completed at puberty and a normal adult male or female develops.

In the adult there is a marker for the genetically normal female cell. The nucleus of such a cell contains a darkly staining mass at its edge. This mass, called the X chromatin or Barr body, is an inactive X chromosome. During normal cell activity the DNA of only one X chromosome participates; the other persists only as an inactive Barr body. Such chromatin masses are not found in normal genetic males because they have only one active X chromosome for the cell nucleus. Not the same X chromosome becomes inactive in every cell of a normal female, so that some cells express the X chromosomal activity of the father while others express that of the mother. In effect, every normal female is what is called a mosaic, an individual whose active chromosomal components vary from one cell to another. This state of affairs is known as the Lyon hypothesis.

Barr body

It should be mentioned that sexual differentiation occurs in the hypothalamus as well. During the newborn period, exposure to androgen leads to a pulsatile but otherwise unvarying secretion of hypothalamic gonadotropin-releasing hormone throughout adult life. In contrast, the lack of a neonatal androgen influence leads in the mature female to the characteristic monthly cycles of GnRH secretion, reflected in normal menstrual cycles.

In such a complex system there are many opportunities for some form of aberrant development. The causes of these disorders, while not fully understood, have been greatly elucidated by rapid advances in chromosomal analysis, the identification of isolated genetic defects in steroid hormone synthesis, and an expanded understanding of abnormalities in steroid hormone receptors. When techniques became available for microscopic examination of the full complement of individual chromosomes, soon followed by sophisticated fluorescent staining techniques, a good deal of confusion surrounding the clinical distinctions among abnormalities of sexual differentiation were resolved.

Klinefelter's syndrome. Klinefelter's syndrome (47,-XXY seminiferous tubule dysgenesis) is the most frequent chromosomal disorder (occurring in one in 1,000 males). Symptoms and features were first described in 1942 by the American physician Harry F. Klinefelter, a student of Fuller Albright. It later became known that affected individuals had an extra X chromosome in each cell so that the sex chromosome content was XXY and the total number of chromosomes in each cell was 47 rather than 46. Viewed under the microscope, the cells of these individuals contain Barr bodies because, as in normal females, one of the two X chromosomes is inactive.

These patients have the outward appearance of males with firm, small testes. They cannot generate sperm, and they often have enlarged breasts and buttocks and inordinately long legs. Testosterone production is deficient and there is a compensatory increase in the pituitary gonadotropin secretion. While normal in intelligence, some of these persons have difficulties in making social adjustments. Klinefelter's syndrome occurs more often in the children of mothers over the age of 35 years.

Symptoms of Klinefelter's syndrome

The mosaic form of Klinefelter's syndrome (46,XY/47,-XXY) is the second most common type of chromosomal disorder in males. Such persons generally have fewer symptoms than do patients with the complete syndrome. Far rarer variants occur, including 48,XXYY; 48,XXXY; 49,-XXXYY; and 49,XXXXY. These patients suffer from a variety of additional abnormalities and, unlike those with classical Klinefelter's syndrome, they are always mentally retarded. Another variant is the XX male syndrome. Such persons show changes typical of Klinefelter's syndrome. Apparently they have Y chromosome material transferred to one of the autosomes. Treatment with androgens serves to reduce the gynecomastia and evidence of male hypogonadism while increasing the strength and libido of all variants of Klinefelter's syndrome.

Turner's syndrome. Turner's syndrome (gonadal dysgenesis) occurs as a result of a deletion of a sex chromosome so that in the typical patient there is a 45,X chromosomal complement. In genetic terms, these individuals are neither male nor female since the second, sex-determining chromosome is absent. Without a Y chromosome to direct fetal gonads to the male configuration, they develop as females with no Barr bodies demonstrable in cell nuclei. Clinically, they tend to resemble one another—with a small chin and prominent folds of skin at the inner corners of the eyes (epicanthal folds), low-set ears, a short neck with redundant skin (webbed neck), a shieldlike or square chest, and short stature. Both the internal and external genitalia are infantile, and the gonads are present only as "streaks" of connective tissue.

If untreated these patients fail to develop secondary sex characteristics, and they are susceptible to a number of threatening congenital abnormalities of the heart and large blood vessels. Turner's syndrome, in genetic terms, is extremely common since one-tenth of all spontaneously aborted fetuses have a 45,X constitution; only 3 percent of afflicted fetuses survive to term.

It is possible to use growth hormone to increase ultimate height of patients with Turner's syndrome, but it is more important to treat them with estrogens at the time of puberty. This leads to the appearance of secondary sexual characteristics along with monthly vaginal bleeding simulating a menstrual cycle. Aside from the psychosocial benefits, estrogen treatment prevents the emergence of the severe osteoporosis found in untreated patients.

Treatment of Turner's syndrome

As with Klinefelter's syndrome, Turner's syndrome has multiple variants in its chromosomal constitution, which include mosaics and chromosomal translocations (in which a portion of one chromosome is transferred and attached to one of the arms of another chromosome). A frequent variant is the 45,X/46,XY mosaic, in which an individual may be reared as either a male or a female because the genitalia are "ambiguous," it being difficult to determine whether the phallus is an enlarged clitoris or a small penis. These patients also have streak gonads with an increased risk that they will undergo a malignant change.

Rarely, patients with 46,XY or 46,XX chromosome complements are found to have streak gonads, and they never develop secondary sexual characteristics, although they are spared the skeletal changes associated with Turner's syndrome.

True hermaphrodites

Hermaphroditism. Hermaphroditism is, in strict medical terms, quite rare. A true hermaphrodite is an individual who harbours ovarian and testicular tissue, both clearly defined when examined under a microscope. Separate ovarian and testicular tissue may be present, or the two tissues may be combined in an ovotestis. Most often, but not always, the chromosome composition is 46,XX, and in every such individual there also exists evidence of Y chromosomal material on one of the nonsex chromosomes (autosomes). These individuals usually have ambiguous external genitalia with a sizable phallus so that, generally, they are reared as males. They develop breasts during puberty and menstruate. In some instances even pregnancy and childbirth have occurred. Spermatogenesis is rare.

Treatment depends upon the age at which the diagnosis is made. If it is decided that a male identity is deeply embedded and therefore a male role is preferable, all female tissues, including the oviducts and ovaries, are removed. In those persons to be reared as females, the male sexual tissues are removed. In older patients, the accepted gender should be reinforced by the appropriate surgical procedures and hormonal therapy.

There exist rare sex chromosome abnormalities that are not associated with any gonadal defects. These include 47,XXX; 48,XXXX; and even 49,XXXXX. People with such abnormalities are usually mentally retarded, and the diagnosis is often made by the finding of multiple Barr bodies in the nuclei of cells of patients confined in mental hospitals. Males with a 47,XYY complement were long thought to be predestined to become tall men with severe acne who commit violent crimes (XYY syndrome). Later studies have documented that these predictions were greatly exaggerated. Although there appears to be a somewhat increased risk of aberrant behaviour, the majority of such men behave in an entirely normal fashion.

Hormonal causes

Female pseudohermaphroditism. Genetic females (46,-XX) who often are assigned the male gender have in the past been produced by hormones used to sustain pregnancy. If, in the first trimester of pregnancy, a mother is administered androgens, progestogens, anabolic steroids such as Danazol, or even the synthetic estrogen stilbestrol, her female child may be masculinized during fetal development. Androgen-producing tumours of either adrenal or ovarian origin may also lead to masculinization of the female fetus. (For discussion of female pseudohermaphroditism due to an enzyme defect in the adrenal cortex, see above *The adrenal cortex.*)

Male pseudohermaphroditism. Male pseudohermaphrodites are genetic males (45,XY) who develop female configurations and identities. The gonads are testes, but the genital ducts and external genitalia are female. Secondary sex characteristics may never appear in some patients, while others may achieve a fully feminized physique. Male pseudohermaphroditism is rare and almost always results from genetic defects, usually autosomal recessive in type. Although a number of specific defects lead to feminization of a genetic male, they all share, by one mechanism or another, a loss of androgenic effects on body tissues. In a few rare instances Leydig cells are absent or greatly reduced in number, presumably because the receptors for LH are defective; without Leydig cells little testosterone is produced. In other patients there are enzymic deficiencies analogous to what occurs in female pseudohermaphrodites (see above *The adrenal cortex*), but in this instance resulting in fetal androgen deficiency.

Complete testicular feminization

In some patients, tissue receptors for androgens are absent or reduced, forming a spectrum of syndromes of partial to complete resistance to androgens. Perhaps the most striking example is complete testicular feminization. Affected patients are born with female genitalia and a vagina that ends blindly. They have well-defined testes located either in the labia or within the abdomen; nevertheless, they grow into well-proportioned, attractive females with normal breasts and scant or absent axillary and pubic hair. They have a strong female orientation, but they do not menstruate. The hormonal aberrations in these patients are dramatic and predictable. With a loss of hypothalamic and pituitary androgen receptors there is no inhibin of gonadotropin secretion, and plasma LH levels remain elevated and lead to enhanced stimulation of the Leydig cells. In consequence, serum testosterone levels are much elevated, and Leydig cells are greatly increased in number. The FSH levels are usually normal, probably due to increased inhibin production by Sertoli cells. The peripheral conversion in tissues of the increased amounts of testosterone to estrogens leads to an increase in estrogen levels above normal values for males.

In another extraordinary variant, the lesion lies not in the loss of androgen receptors but rather in a loss of the 5 α-reductase, an enzyme necessary for the conversion of testosterone to the more potent hormone dihydrotestosterone. In this syndrome, because of a lack of testosterone directing fetal development toward a normal male configuration, genetic males are born with what appears to be female genitalia with an enlarged clitoris. These persons are often raised as females, but at puberty an increase in testosterone secretion leads to clear-cut masculinization without enlarged breasts. There then ensues a transition from a prepubertal female to an adult male. This change in gender identity takes place apparently without undue emotional turmoil.

Vanishing testes syndrome

In some fetuses there occurs, for unknown reasons, a regression and disappearance of the testes of genetic males, the "vanishing testes syndrome." When this occurs early in pregnancy and before androgen-induced differentiation toward male genitalia, the child is born with female genitalia. If the testes disappear during the crucial period between eight and 10 weeks of gestation, the child is born with ambiguous genitalia, whereas if the disappearance occurs after this key period, the individual is a male, but without any testes (anorchia).

Treatment of such persons must be highly individualized. In most instances, the gender identity has been firmly implanted by the age of 18 months, and sexual changes are attempted only after careful consideration. Intra-abdominal testes should be removed because of an increased risk of tumour formation. The patient can be treated at the appropriate time with sex hormones.

Homosexuality and transsexualism. The genesis of homosexual and transsexual behaviour is complex and poorly understood. Undoubtedly, environmental and psychosocial influences play important roles, but only the rather meagre knowledge of endocrine influences is discussed here. While early studies suggested a number of abnormalities in homosexual males, including low serum testosterone levels and abnormal ratios of several steroid hormones, later, more stringent investigations generally have not confirmed these differences. It is clear that treatment of male homosexuals with androgens may increase the sexual drive but only in the direction that had been accepted previously.

Recent theories

There is more recent evidence from studies in animals and from inferential studies in humans that severe emotional stress in mothers early in pregnancy may lead to homosexuality in their male offspring. In some studies, elevated serum testosterone levels were found in female homosexuals, while in others no differences were found. Generally, endocrine function has been found to be normal in transsexual men; however, some studies have indicated that these individuals have mildly elevated serum LH levels along with a hyperresponsiveness to the stimulation of LH by GnRH.

It may well be that these confusing conclusions result from the study of heterogeneous populations. Some homosexual behaviour may be predetermined by aberrant hormonal influences during pregnancy while others may be a response to environmental influences. If so, divergent, indeterminate results of hormonal studies would not be surprising.

THE PINEAL GLAND

The pineal gland, the most enigmatic of endocrine organs, has long been of interest to anatomists. Several

millennia ago it was thought to be a valve that controlled the flow of memories into consciousness. René Descartes, the 17th-century French philosopher-mathematician, concluded that the pineal was the seat of the soul. A corollary notion was that calcification of the pineal caused psychiatric disease, a concept that provided support for those who considered psychotic behaviour to be rampant; modern examination techniques have revealed that all pineal glands become more or less calcified.

Anatomy. The pineal organ is small, weighing little more than 0.1 gram. It lies deep within the brain between the two cerebral hemispheres and above the third ventricle of the spinal column. It has a rich supply of adrenergic nerve fibres that greatly influence its secretions. Microscopically, the gland is composed of pinealocytes (rather typical endocrine cells except for extensions that mingle with those of adjacent cells). Supporting cells that are similar to astrocytes of the brain are interspersed.

Hormones. The pineal gland contains a number of peptides, including GnRH, TRH, and vasotocin, along with a number of important neurotransmitters such as somatostatin, norepinephrine, serotonin, and histamine. The major pineal hormone, however, is melatonin, a derivative of the amino acid tryptophan. Melatonin was first discovered because it lightens amphibian skin, an effect opposite to that of melanocyte-stimulating hormone of the anterior pituitary. Secretion of melatonin is enhanced whenever the sympathetic nervous system is stimulated. Of greater interest, however, is the fact that secretion increases soon after an animal is placed in the dark; the opposite effect takes place immediately upon exposure to light. Its major action, well documented in animals, is to block the secretion of GnRH by the hypothalamus and of gonadotropins by the pituitary. While it was long thought that a decrease in melatonin secretion heralded the onset of puberty, this hypothesis cannot be supported by studies in humans. It is possible that the pineal contains an as yet unidentified hormone that serves that function.

Melatonin

Pineal tumours. Pineal tumours are rare, occurring most often in children and young adults. The most common of these are germ cell tumours (germinomas and teratomas), which arise from embryonic remnants of germ cells. These tumours are malignant and invasive and may be life-threatening. Tumours of pinealocytes also occur and vary in their potential for malignant change.

Pineal tumours may cause headache, vomiting, and seizures due to the increase in pressure within the head that results from the enlarging tumour mass. Endocrinologic effects may also be observed. Some patients may become hypogonadal with regression of secondary sex characteristics, while others may undergo precocious puberty because of secretion of chorionic gonadotropin. Diabetes insipidus is frequently associated and is usually due to tumour invasion of the hypothalamus and posterior pituitary. Invasion of the pituitary stalk may interfere with the ongoing inhibition of prolactin secretion by dopamine from the hypothalamus, resulting in elevated serum prolactin levels, a finding that may lead to a mistaken diagnosis of prolactinoma. Treatment consists of surgical relief of the increased intracranial pressure and X-ray therapy.

HORMONES OF THE INTESTINAL MUCOSA

In 1902, two English physiologists, Sir William M. Bayliss and Ernest H. Starling, placed dilute hydrochloric acid into a segment of a dog's bowel from which the nerve supply had been severed. They then scraped off the bowel lining, boiled it, filtered it, and injected the filtrate into a dog's vein. The injection was followed shortly by a greatly increased secretion of pancreatic juices. They named the unidentified water-soluble material in the filtrate "secretin," and thus was modern endocrinology born. With this discovery emerged the pivotal concept of chemical messages acting at a distant site to regulate bodily functions. Interest in secretin soon waned, however, overshadowed by discoveries in what became the mainstream of endocrinology. It was not until the advent of modern techniques for isolating, characterizing, and measuring protein hormones that interest in the endocrinology of the gastrointestinal tract was revived. It has become clear that the intestinal tract is not only a complex system dedicated to the digestion and absorption of nutrients but also a large endocrine organ that secretes many hormones.

Secretin. Secretin, a polypeptide containing 27 amino acids, is concentrated in the lining of the upper intestine. When hydrochloric acid from the stomach passes into the duodenum, secretin is released into the blood and soon prompts the pancreatic acinar cells to release water and bicarbonate into the pancreatic ducts and from there into the duodenum. By this mechanism, hydrochloric acid, which can be damaging to intestinal lining, is promptly diluted and neutralized by the pancreatic water and bicarbonate. Secretin is used as a stimulator of the pancreas to evaluate exocrine pancreatic functions of patients.

Neutralizing hydrochloric acid

Gastrin. Gastrin is a 17-amino-acid polypeptide that is secreted into the circulation by cells lining the stomach. Gastrin stimulates the secretion of hydrochloric acid and a digestive enzyme, pepsin, into the stomach cavity, while simultaneously increasing the contractions of its distal part. The medical significance of gastrin lies in the fact that there are pancreatic islet cell tumours that secrete large quantities of gastrin or its prohormone, "big gastrin." The affected patient has severe peptic ulcer disease that is unresponsive to the usual forms of treatment. There is often associated diarrhea with bowel movements containing large amounts of fat. Gastrinomas often form part of the syndrome of multiple endocrine neoplasia (MEN I) discussed below. Treatment consists of removing the tumour surgically when feasible or, when not, of cutting the vagus nerve, followed by the administration of a gastric-acid-inhibiting drug such as cimetidine.

Gastric inhibitory polypeptide. Gastric inhibitory polypeptide (GIP) is a hormone secreted by cells of the intestinal mucosa that blocks the secretion of hydrochloric acid into the stomach. It also serves to enhance insulin secretion from the beta cells of the islets of Langerhans so that plasma insulin levels rise after a meal even before the ingested glucose or amino acids enter the blood, an example of an anticipatory hormonal action.

Cholecystokinin. The secretion of cholecystokinin (CCK) is stimulated by the introduction of hydrochloric or fatty acids into the stomach or duodenum. As its name implies, cholecystokinin stimulates the gall bladder to contract and release stored bile into the intestine. Similarly, it stimulates the flow of pancreatic juices. There is interest in the possibility that intestinal hormones, particularly CCK, may induce satiety. According to this hypothesis, after a person eats a meal, the secreted CCK stimulates the satiety centre of the hypothalamus so that the individual "feels full" and stops eating. Because CCK is also known to contract the muscles of the channel leading from the stomach into the duodenum, thus inhibiting gastric emptying, it is possible, however, that people have the feeling of being full simply because of gastric distension.

Vasoactive intestinal polypeptide. Vasoactive intestinal polypeptide (VIP), a 28-amino-acid polypeptide, is secreted by cells throughout the intestinal tract. It acts to change the activity of the intestinal mucosa so that water and electrolytes are secreted rather than absorbed as usual.

Effect on intestinal mucosa

Pancreatic islet cell tumours that secrete excessive amounts of VIP are called VIPomas (Verner-Morrison syndrome). Affected persons have a severe, intractable, debilitating watery diarrhea with an associated loss of large quantities of potassium. If the patient is unable to replace the lost fluids adequately, the resulting dehydration may become life-threatening, leading to use of the term pancreatic cholera. Removal of the tumour and postsurgical chemotherapy has improved the survival rate considerably, even though metastases occur in about one-third of these patients.

Other gastrointestinal hormones also serve as neurotransmitters in the brain, but they have not been found to produce disease. These hormones include katacalcin, caerulein, motilin, neuropeptide Y, and gastrin-releasing peptide (bombesin-like peptide). Glucagon (see above *The pancreas*) and somatostatin (see above *The hypothalamus* and *The pancreas*) also serve as gastrointestinal hormones and brain neurotransmitters, and they also produce rare hyperfunctioning pancreatic tumours.

PROSTAGLANDINS

The prostaglandins (PGs) are a common group of modified fatty acids that are astonishingly diverse in their actions; for the most part, they have a local (paracrine) function. The study of these powerful agents had modest beginnings when, in 1935, a Swedish physiologist and Nobel laureate, Ulf von Euler, and other investigators found that extracts of seminal vesicles or of human semen lowered blood pressure and caused contraction of strips of uterine tissue. Von Euler coined the term prostaglandin because he assumed that the active material came from the prostate gland.

The prostaglandins comprise a group of related cyclic, unsaturated fatty acids that are derived primarily from the 20-carbon, straight-chain, polyunsaturated fatty acid precursor, arachidonic acid. Each prostaglandin differs from the others in subtle changes in chemical structure or side-chain substitutions; these differences are responsible for the different biologic activities of the members of the prostaglandin group.

Arachidonic acid

Arachidonic acid is a key component of the phospholipids, which are themselves integral components of cell membranes. In response to a variety of stimuli, a chain of events is set in motion that results in prostaglandin release (Figure 15).

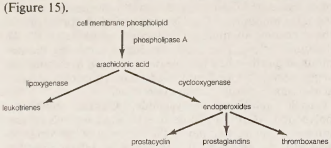


Figure 15: Synthetic pathways of arachidonic acid breakdown from phospholipids of the cell membrane.

The actions of an enzyme, phospholipase A, induce the phospholipids to release the precursor, arachidonic acid. One enzyme, lipoxygenase, catalyzes the synthesis of the leukotrienes. Another enzyme, cyclooxygenase, stimulates the conversion of arachidonic acid to several endoperoxides. The endoperoxides undergo further biosynthesis to the prostaglandins, prostacyclin, and the thromboxanes. (The thromboxanes and prostacyclin are important compounds that have functions in the process of blood coagulation. Leukotrienes, converted from endoperoxides in white blood cells, or leukocytes, are important mediators of the inflammatory process.)

The actions of the prostaglandins are multiple and variable; the same prostaglandin might stimulate a reaction in one tissue and inhibit it in another. Prostaglandin effects are usually manifested locally around the site of prostaglandin synthesis.

When the actions of prostaglandins are stimulatory, they act as intermediaries (necessary elements that elicit a subsequent step along a synthetic or biologic pathway) in the formation of cyclic 3′,5′-adenosine monophosphate (cyclic AMP, cAMP), and thus the final biologic actions of the target cells.

This synthetic pathway begins when tropic hormones (hormones of one endocrine gland that affect the actions of other endocrine structures) are bound to receptors on the surface of the cells of the target organ. These tropic hormones, called first messengers, initiate the prostaglandin-synthesis pathway discussed above, and the increased concentration of prostaglandins around the target organ stimulates the intracellular synthesis of cAMP from adenosine triphosphate (ATP), a process that brings about the biologic action of the target organ. Unaccountably, prostaglandins may inhibit the synthesis of cAMP in some tissues.

Vasodilator effect

Prostaglandins are powerful vasodilators; that is, they relax the muscles in the walls of blood vessels so that the diameters become larger and there is less resistance to the flow. Consequently, the blood pressure falls. Again, the effect can be local. An important example of the vasodilation effect of prostaglandins is found in the kidney, where widespread vasodilation leads to an increase in the flow of blood to the kidney and an increased excretion of salt in the urine. Thromboxanes, on the other hand, are powerful vasoconstrictors in the same setting.

Some diuretics, such as furosemide, probably act by releasing prostaglandins in the kidney. Prostaglandins inhibit the action of vasopressin on the kidney tubules, resulting in enhanced urinary excretion of water. The resultant tendency to dehydration from this enhanced excretion of water leads to local secretion of another kidney prostaglandin that stimulates the secretion of renin (see above *The adrenal cortex: Aldosterone*). Renin stimulates the production of aldosterone, which has the affect of conserving sodium and water, thus combating the dehydration and elevating the depressed blood pressure.

Although prostaglandins were first detected in semen, no biologic role for them has been defined in the male reproductive system. This is not true, however, for females. It has been shown that prostaglandins mediate the control of GnRH over LH secretion, modulate ovulation, and stimulate uterine muscle contraction. Discovery of this last property has led to the successful treatment of menstrual cramps (dysmenorrhea) through the use of inhibitors of prostaglandin synthesis, such as ibuprofen. Prostaglandins also play a role in inducing labour in pregnant women at term or in inducing therapeutic abortions.

The process of clot formation begins with an aggregation of blood platelets. This process is strongly stimulated by thromboxanes and inhibited by prostacyclin. Prostacyclin is synthesized in the walls of blood vessels and serves the physiological function of preventing needless clotting. Thromboxanes, on the other hand, are synthesized within the platelets themselves and are released. The platelets adhere to one another and to blood vessel walls. Through prostaglandin and thromboxane mechanisms, clotting is prevented when it is unnecessary and takes place when it is necessary. Platelets adhere in arteries that are affected by the process of atherosclerosis; they form plaques along the interior surface of the vessel wall. This type of platelet aggregation and clotting leads to blocking (occlusion) of the vessel wall, the most common cause of heart attack (coronary artery occlusion). This biologic insight has led to the widespread recommendation that those at risk for a coronary occlusion take aspirin, an inhibitor of the enzyme cyclooxygenase, daily as a preventive measure.

Role in inflammation

Prostaglandins also play a pivotal role in inflammation, a process characterized by the ancient Romans as consisting of redness (*rubor*), heat (*calor*), pain (*dolor*), and swelling (*tumor*). These changes are due to a local dilation of blood vessels that permits increased blood flow to the affected area. The blood vessels become more permeable, leading to the escape of infection-fighting fluid and white blood cells from the blood into the surrounding tissues. These changes are mediated by prostaglandins, particularly the subgroup called leukotrienes. Thus, effective treatment to suppress inflammation in inflammatory but noninfectious diseases, such as rheumatoid arthritis, is to treat the patient with inhibitors of prostaglandin synthesis, such as aspirin. Similarly, the pain and fever of other disseminated inflammations can be alleviated by these nonsteroidal anti-inflammatory drugs.

Another crucial mechanism of the body that protects it from invasion by bacteria, viruses, or other noxious agents is known as the immune response. It begins when a foreign substance is ingested by a mobile, scavenging, white blood cell, called a macrophage. The macrophage interacts with a special white blood cell called a T-lymphocyte (T cell), which in turn activates B-lymphocytes (B cells or plasma cells). The result is that the B cell elaborates and secretes specific proteins (antibodies) that are designed to make the ingested foreign invader more susceptible to attack and ingestion by other white blood cells.

In cellular immune response, T cells become activated at the site of damage and release proteins called lymphokines, which attract macrophages to the local area and stimulate them to ingest the offending agents. Prostaglandins generally attenuate the immune response by inhibiting both T cell and B cell activity, but some prostaglandins, particularly the leukotrienes, enhance inflammatory responses.

The understanding of the immune response marks a ma-

Anaphylactic reactions

jor advance in medicine since aberrations in this response cause hypersensitivity (anaphylactic) reactions, allergies, and autoimmune diseases. Examples include harmful reactions to drugs such as penicillin; hay fever; bronchial asthma; rheumatoid arthritis; Graves' disease; and autoimmune endocrine deficiency diseases. Prostaglandins play important roles in the genesis of these disorders, an awareness that has led to the development of a number of powerful inhibitors of prostaglandin synthesis for use in treatment.

The functioning of the digestive tract is also influenced by prostaglandins. Depending on the setting, various prostaglandins may either enhance or inhibit the contraction of the smooth muscles of the intestinal walls. They are also powerful inhibitors of stomach secretions, perhaps because they inhibit the secretion of the stomach hormone gastrin, which stimulates gastric secretion. It is not surprising, then, that drugs, like aspirin, which inhibit prostaglandin synthesis may lead to peptic ulcers. Prostaglandin action on the digestive tract may cause a severe watery diarrhea and may mediate the effects of vasoactive intestinal polypeptide (VIP) in the Verner-Morrison syndrome (see above *Hormones of the intestinal tract*), as well as the effects of cholera toxin.

Prostaglandins induce several effects on endocrine function. Perhaps of greatest importance is the ability of prostaglandins to stimulate the resorption of bone in diseases such as rheumatoid arthritis and to cause hypercalcemia, particularly in patients harbouring malignant tumours.

The therapeutic applications of the prostaglandins and of the drugs that inhibit prostaglandin synthesis are listed in Table 3. The drugs fall into two categories. In the first are agents like hydrocortisone and its synthetic derivatives, such as prednisone, which stabilize cell membranes and, in large doses, block the liberation of arachidonic acid. In the second are drugs that block the action of the enzyme cyclooxygenase. Among these are aspirin, acetaminophen, indomethacin, and ibuprofen.

Table 3: Therapeutic Applications of the Prostaglandins*

prostaglandins	PG synthesis inhibition
Current	
Midtrimester abortion	Rheumatoid arthritis
Peripheral vascular disease	Fever and headache
Hemodialysis	Bartter's syndrome
Induction of labour	Patent ductus arteriosus
Potential	
Hypertension	Hypercalcemia of malignant disease
Congestive heart failure	Periodontal inflammation
Infertility	Cholera and certain diarrheal states
Coronary and deep thrombosis	Burns
Peptic ulceration	Lupus erythematosus
Gastric hyperacidity	Glaucoma
Bronchial asthma (PGE)	Migraine headache
Nasal congestion	Bronchial asthma (leukotriene)

*From J.D. Wilson and D.W. Foster (eds.), *Williams Textbook of Endocrinology*, 7th ed., Philadelphia, W.B. Saunders Co., 1985. Reprinted by permission.

ECTOPIC HORMONE AND POLYGLANDULAR DISORDERS

In discussing general characteristics of endocrine hyperfunction above it was indicated that the cells of endocrine glands, following long-term stimulation, increase in size (hypertrophy) and number (hyperplasia). If the stimulation persists, these cells may be transformed into a tumour, which may be either benign or malignant.

Tumour development

For reasons that have aroused much speculation but remain poorly understood, these changes may occur in more than one endocrine gland, simultaneously or consecutively, even though the embryonic origin of the cells of the other endocrine glands that are involved may be different, and even though this propensity to tumour formation is confined to endocrine glands only (multiple endocrine neoplasia). Similarly, for equally obscure reasons, multiple endocrine glands may be attacked by autoantibodies with the result that the patient is afflicted with multiple hormonal deficiencies (multiple endocrine deficiency syndromes). Finally, there have emerged syndromes due to excessive amounts of hormones produced by tumours of tissues that do not ordinarily produce hormones at all (ectopic hormone production). This transformation initially was thought to occur when the tumours activated genes that generated these hormones, and that ordinarily were repressed in the cell of the nonendocrine tissue. Recent evidence has revealed that most tissues synthesize small amounts of most hormones and, indeed, other substances that have no hormonal activity, so that the change that occurs following tumour formation is a quantitative rather than a qualitative one.

Multiple endocrine neoplasia. Multiple endocrine neoplasias (MEN) are hereditary disorders usually occurring in an autosomal dominant genetic distribution (*i.e.*, the defect is not tied to the sex of the individual and statistically, one-half of the children of an affected person will also be affected) so that families are heavily sprinkled with affected individuals. There are several defined patterns of glandular involvement which usually, but not always, "breed true" in that the clusters of glandular involvement follow the same groupings from one family member to another. Studies of distribution in humans are necessarily incomplete because the endocrine tumours do not appear simultaneously. Thus, a patient who may appear to have an incomplete expression of one of these inherited syndromes when first examined may later develop the full clinical picture.

Principal glands involved

The first described and the most frequently occurring of these unusual disorders is multiple endocrine neoplasia type I (MEN I). The principal glands involved in this syndrome are the parathyroids, the pancreatic islets, and the anterior pituitary. All four parathyroid glands are involved either by hyperplasia alone or a mixture of hyperplasia and adenomas. The symptoms of hyperparathyroidism may be mild and are often overshadowed by the disabling problems engendered by the islet cell tumours. Two-thirds of patients with MEN I develop gastrinomas with severe, intractable peptic ulcers. Insulinomas with severe hypoglycemia also occur frequently, and in some patients both tumours arise. The pituitary manifestations are most frequently those of prolactinoma or acromegaly (see above *The anterior pituitary*). Involvement of the adrenal cortex and the thyroid glands may occur, but it is possible that these aberrations are coincidental rather than an integral part of the hereditary disease. Treatment consists of attacks on individual hyperfunctioning glands as they appear; however, in contrast to sporadic cases, it is important to counsel families to have all members screened for evidence of MEN I because early treatment is more effective and less risky.

Multiple endocrine neoplasia type II (MEN II) is composed of another distinct constellation of glandular involvements: a medullary carcinoma of the thyroid; pheochromocytoma, usually bilateral; and, again, hyperparathyroidism. Medullary carcinomas of the thyroid arise from the parafollicular C cells (see above *The thyroid gland*), which secrete calcitonin (see above *The parathyroid glands*). Medullary thyroid carcinoma occurs in all affected families except those who, by screening techniques, are detected at an early stage when C cell hyperplasia has not yet been transformed into a carcinoma. Medullary thyroid carcinoma is an example of ectopic hormone production in that these tumours may elaborate excessive quantities not only of the expected hormone, calcitonin, but also ectopically of other bioactive substances, including corticotropin, prostaglandins, serotonin, and the neurotransmitter substance P. While only a small minority of all patients harbouring pheochromocytoma have MEN II, when these tumours do occur in both adrenal glands, the likelihood is much greater that MEN II is present. As in the case of C cells, adrenal medullary hyperplasia precedes the development of true tumour formation. The high blood pressure and other symptoms characteristic of pheochromocytoma have been described previously (see above *The adrenal medulla*), and, again, parathyroid hyperplasia occurs more frequently than parathyroid tumours in this syndrome. Early screening of family members is strongly recommended, and treatment does not

differ from that applied to patients with a single hyperfunctioning endocrine gland.

MEN IIB

A variant of MEN II is termed MEN IIB, or MEN III. Patients with this disease also suffer from medullary thyroid carcinoma and pheochromocytoma, but they differ in that hyperparathyroidism rarely occurs, and affected family members uniformly develop mucosal neuromas. These are nerve tumours, usually benign, involving the lips and linings of the mouth, nose, and throat. They may be recognized at birth or in early childhood as "bumpy lips," and these neuromas may be scattered throughout the gastrointestinal tract, causing constipation and, less frequently, vomiting and difficulty in swallowing.

On rare occasions, some patients with multiple endocrine neoplasia do not fit established patterns. Some of these aberrations may be explained by coincidence, but others seem to represent true MEN of a mixed type, for example, pheochromocytoma associated with pancreatic islet cell tumours.

Multiple endocrine deficiency syndromes. In multiple endocrine deficiency syndromes, affected families have some or all of a bewildering array of ailments shown in Table 4. Investigators have found it convenient to divide these deficiency diseases into two types, although, from inspection of the Table, it can be seen that there is considerable overlap. Type II is inherited in an autosomal-dominant pattern, while type I is thought to be due to autosomal-recessive inheritance. What is inherited in both types is the propensity to develop circulating autoantibodies directed against, and destroying, one or more of the tissues listed in Table 4.

Table 4: Autoimmune Polyglandular Syndromes*

type II	type I
Hyperthyroidism	Hypoparathyroidism
Hypothyroidism	Yeast (*Candida*) infection of the skin and mucous membranes
Diabetes, type I	Adrenal insufficiency
Adrenal insufficiency	Hepatitis
Myasthenia gravis	Malabsorption
Celiac disease	Vitiligo
Hypogonadism	Pernicious anemia
Pernicious anemia	Alopecia
Vitiligo (skin depigmentation)	Hypothyroidism
Alopecia	

*Adapted from J.D. Wilson and D.W. Foster (eds.). *Williams Textbook of Endocrinology*. 7th ed., Philadelphia, W.B. Saunders Co., 1985. Reprinted by permission.

These autoantibodies (see above *The human endocrine system: Endocrine dysfunction*) may be detected in the blood many years before the discernible disease appears. The apparently paradoxical appearance of hyperthyroidism in type II results from the development of circulating thyroid-stimulating autoantibodies. Type II diseases are distinguishable from type I in that multiple generations are affected, the highest incidence occurring between the ages of 20 and 60, and that affected individuals are not afflicted with mucocutaneous candidiasis (a fungal infection of the mucous membranes and skin). Type I, in contrast, has its onset in infancy or childhood, it is commonly associated with candidiasis, and it is characterized by the appearance of the disease in siblings but without transmission from one generation to the next. Treatment is directed toward each individual abnormality.

Onset of MEN syndromes

Ectopic hormone production. Previous views that it is rare for excessive quantities of hormones to be secreted by tumours of nonendocrine origin have been supplanted by demonstrations that ectopic hormone production is indeed quite common (Table 5). Ectopic corticotropin production, the most common of these syndromes, is most frequently associated with carcinoma of the lung, carcinoma of the thymus, or islet cell tumour; however, it may also occur in association with a long list of other neoplasms, including pheochromocytoma, bronchial adenoma, medullary thyroid carcinoma, and carcinomas of the ovary, prostate, breasts, kidney, testes, gallbladder, and even of the appendix. Patients usually have the intense pigmentation and severe depletion of potassium that is characteristic of overproduction of ACTH and of mineralocorticoids. In addition the excessive tissue breakdown characteristic of Cushing's syndrome is added to the debilitating effects of the cancer itself. Treatment ordinarily involves removal or destruction of the cancer, but occasionally, when the tumour cannot be completely removed, an attack on the overactive adrenals, either with drugs or by surgical removal, is warranted.

Table 5: Hormones and Hormone Precursors Reported to be Produced by Neoplasms*

ACTH, lipotropin, and pro-opiomelanocortin
Corticotropin-releasing hormone
Chorionic gonadotropin and its subunits (α and β)
Vasopressin
Growth factors (*e.g.* IGF)
Parathyroid hormonelike materials
Osteoclast-activating factor
Erythropoietin
Eosinophilopoietin
Growth hormone
Growth hormone-releasing hormone
Prolactin
Gastrin
Gastrin-releasing peptide (and bombesin)
Secretin
Glucagon
Calcitonin
Renin
Vasoactive intestinal peptide
Somatostatin
Hypophosphatemia-producing factor
Prostaglandins
Estrone and estradiol

*From J.D. Wilson and D.W. Foster (eds.), *Williams Textbook of Endocrinology*. 7th ed., Philadelphia, W.B. Saunders Co., 1985. Reprinted by permission.

Chorionic gonadotropin

The synthesis of chorionic gonadotropin (a hormone produced by the placenta that stimulates the gonads) originally was thought to be confined to one of the membranes covering the fetus. Recent, more sensitive testing, however, has revealed that at least one segment of this hormone is synthesized in almost all tissues. Chorionic gonadotropin is a glycoprotein similar to TSH, LH, and FSH in that it contains both alpha and beta chains. It is likely that it is a fragment of the beta chain that is found in tumour tissues. As much as 13 percent of all carcinomas are associated with increased circulating levels of chorionic gonadotropin-like material. Affected patients may have no symptoms or may have symptoms similar to those produced by excessive LH secretion.

There are numerous other manifestations of ectopic hormone production. They include the secretion of bioactive materials that result in hypoglycemia, hypercalcemia, hypocalcemia, and the inappropriate secretion of vasopressin (see above *The posterior pituitary*), growth hormone, and growth-hormone-releasing hormone. As discussed above, treatment is aimed at ablating or reducing the activity of the offending tumour or mitigating the effects of the hormone produced in excess.

ENDOCRINE CHANGES WITH AGING

Because the endocrine glands play pivotal roles both in reproduction and in development, it seems plausible to extend the role of the endocrine system to account for the progressive bodily changes that occur with aging (senescence). Indeed, for a time, an "endocrine theory of aging" enjoyed wide popularity among scientists. Early in the 20th century, the possibility that aging could be deferred and virility restored by the injection of crude extracts of monkey glands attracted a good deal of attention. Upon closer scrutiny, however, it has become clear that the endocrine glands weather the ravages of age quite well and, in a number of instances, tend to mitigate its effects. (For a discussion of the aging process, see GROWTH AND DEVELOPMENT, BIOLOGICAL.)

The menopause. The most striking change with age is that of the menopause (see above *The ovary*). Estrogens are produced by granulosa cells and cells of the stroma, which line the egg-containing ovarian follicles. Because the number of these follicles in the ovaries is limited, their depletion with age makes inevitable the reduction in estrogen

Reduced estrogen levels

secretion, which, in endocrinologic terms, defines the onset of the menopause. The low circulating estrogen levels reduce hypothalamic and pituitary inhibition of GnRH, LH, and FSH secretion so that circulating levels of these hormones undergo a striking and sustained elevation; a three- to fourfold increase above premenopausal values is found in women above the age of 60. Prolactin secretion also increases. Clearly, in normal postmenopausal women, while the ovaries have "failed" to a large degree, the hypothalamus and pituitary have not.

The testis. Reduction in the number of androgen-secreting Leydig cells leads to a tendency toward a decrease in serum testosterone levels, which are compensated for by an increase in gonadotropin secretion. The result is that the healthy, aging male maintains androgen synthesis and secretion at or near normal levels and may father children despite a greatly advanced age. (For further discussion of changes in the gonadal axis in males with age, see above *The testis.*)

Thyroid and adrenal function. Changes in thyroid function with age are subtle and have limited clinical significance. Circulating levels of the thyroid hormone T_4 remain normal while those of the thyroid hormone T_3 tend to decrease. There appears to be reduced responsiveness of TSH-secreting cells to stimulation with thyrotropin-releasing hormone. Some slowing of the metabolic rate may serve well the "weary bones" and tissues of the healthy aged. Similarly, the hypothalamic-pituitary-adrenocortical axis undergoes minor changes but remains intact with advancing years. Plasma cortisol levels remain essentially unchanged. Aldosterone secretion decreases as do plasma renin concentrations, but the healthy elderly are able to maintain normal balances of fluids and electrolytes (see above *The adrenal cortex*).

Growth hormone, parathyroid, and antidiuretic hormones. Growth hormone secretion decreases variably with age. In some healthy elderly persons it is moderately reduced as compared to young adults, and in some otherwise apparently healthy aged individuals there seem to be deficient responses in growth hormone secretion. It is possible, then, that a subpopulation of the aging population may benefit from growth hormone treatment. Serum parathyroid levels seem to rise with age, a change that may serve to maintain normal serum calcium levels. Similarly, the secretion of antidiuretic hormone (vasopressin) tends to be elevated and hyperresponsive. This may occur in response to an increasing difficulty of the aging kidneys to prevent inordinate excretion of water.

Growth hormone

The pancreatic islets. It has been well documented that blood sugar levels, while normal in the fasting state, respond to the ingestion of glucose with increments proportional to the age of the subject; that is, the older the healthy subject, the higher the maximal increase in blood glucose after glucose ingestion. The accompanying increase in levels of serum insulin, although appreciable, is clearly not enough to maintain the glucose levels in the range found in healthy young adults. Whether these changes should be viewed as abnormal or whether they merely reflect modifications appropriate to the aging process remains a matter of debate.

In summary, endocrine changes in healthy aging individuals do not account for the aging process. There is evidence that, with aging, there is a progressive loss in the numbers of hormonal tissue receptors, and, more often than not, there is an appropriate increase in hormone secretion to maintain a healthy homeostatic balance. The case of the failing ovary excepted, the endocrine glands generally sustain their major function of supporting a state of health in the face of declining tissue and organ function until such time as the whole organism falters and decrepitude ensues.

(T.B.S.)

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(T.B.S.)

Energy Conversion

Over the centuries a wide array of devices and systems has been developed for converting energy from forms provided by nature to those most useful to society. Some of these energy converters are quite simple. The early windmills, for example, transformed the kinetic energy of wind into mechanical energy for pumping water and grinding grain. Other energy-conversion systems are decidedly more complex, particularly those that take raw energy from fossil fuels and nuclear fuels to generate electrical power. Systems of this kind require multiple steps or processes in which energy undergoes a whole series of transformations through various intermediate forms.

Many of the energy converters widely used today involve the transformation of thermal energy into electrical energy. The efficiency of such systems is, however, subject to fundamental limitations, as dictated by the laws of thermodynamics and other scientific principles. In recent years, considerable attention has been devoted to certain direct energy-conversion devices, notably solar cells and fuel cells, that bypass the intermediate step of conversion to heat energy in electrical power generation.

This article traces the development of energy-conversion technology, highlighting not only conventional systems but also alternative and experimental converters with considerable potential. It delineates their distinctive features, basic principles of operation, major types, and key applications. For a discussion of the laws of thermodynamics and their impact on system design and performance, see THERMODYNAMICS, PRINCIPLES OF.

For coverage of other related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 112, 123, 124, 127, 711, and 721, and the *Index*.

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FUNDAMENTALS OF ENERGY CONVERSION

General considerations

Definition of energy

Energy is usually and most simply defined as the equivalent of or capacity for doing work. The word itself is derived from the Greek *energeia: en*, "in"; *ergon*, "work." Energy can either be associated with a material body, as in a coiled spring or a moving object, or it can be independent of matter, as light and other electromagnetic radiation traversing a vacuum. The energy in a system may be only partly available for use. The dimensions of energy are those of work, which, in classical mechanics, is defined formally as the product of mass (m) and the square of the ratio of length (l) to time (t): ml^2/t^2. This means that the greater the mass or the distance through which it is moved or the less the time taken to move the mass, the greater will be the work done, or the greater the energy expended.

DEVELOPMENT OF THE CONCEPT OF ENERGY

The term energy was not applied as a measure of the ability to do work until rather late in the development of the science of mechanics. Indeed, the development of classical mechanics may be carried out without recourse to the concept of energy. The idea of energy, however, goes back at least to Galileo in the 17th century. He recognized that, when a weight is lifted with a pulley system, the force applied multiplied by the distance through which that force must be applied (a product called, by definition, the work) remains constant even though either factor may vary. The concept of vis viva, or living force, a quantity directly proportional to the product of the mass and the square of the velocity, was introduced in the 17th century. In the 19th century the term energy was applied to the concept of the vis viva.

Isaac Newton's first law of motion recognizes force as being associated with the acceleration of a mass. It is almost inevitable that the integrated effect of the force acting on the mass would then be of interest. Of course, there are two kinds of integral of the effect of the force acting on the mass that can be defined. One is the integral of the force acting along the line of action of the force, or the spatial integral of the force; the other is the integral of the force over the time of its action on the mass, or the temporal integral.

Evaluation of the spatial integral leads to a quantity that is now taken to represent the change in kinetic energy of the mass resulting from the action of the force and is just one-half the vis viva. On the other hand, the temporal integration leads to the evaluation of the change in momentum of the mass resulting from the action of the force. For some time there was debate as to which integration led to the proper measure of force, the German philosopher-scientist Gottfried Wilhelm Leibniz arguing for the spatial integral as the only true measure, while earlier the French philosopher and mathematician René Descartes had defended the temporal integral. Eventually, in the 18th cen-

tury, the physicist Jean d'Alembert of France showed the legitimacy of both approaches to measuring the effect of a force acting on a mass and that the controversy was one of nomenclature only.

To recapitulate, force is associated with the acceleration of a mass; kinetic energy, or energy resulting from motion, is the result of the spatial integration of a force acting on a mass; momentum is the result of the temporal integration of the force acting on a mass; and energy is a measure of the capacity to do work. It might be added that power is defined as the time rate at which energy is transferred (to a mass as a force acts on it, or through transmission lines from the electrical generator to the consumer).

Conservation of energy (see below) was independently recognized by many scientists in the first half of the 19th century. The conservation of energy as kinetic, potential, and elastic energy in a closed system under the assumption of no friction has proved to be a valid and useful tool. Further, upon closer inspection, the friction, which serves as the limitation on classical mechanics, is found to express itself in the generation of heat, whether at the contact surfaces of a block sliding on a plane or in the bulk of a fluid in which a paddle is turning or any of the other expressions of "friction." Heat was identified as a form of energy by Hermann von Helmholtz of Germany and James Prescott Joule of England during the 1840s. Joule also proved experimentally the relationship between mechanical and heat energy at this time. As more detailed descriptions of the various processes in nature became necessary, the approach was to seek rational theories or models for the processes that allow a quantitative measure of the energy change in the process and then to include it and its attendant energy balance within the system of interest, subject to the overall need for the conservation of energy. This approach has worked for the chemical energy in the molecules of fuel and oxidizer liberated by their burning in an engine to produce heat energy that subsequently is converted to mechanical energy to run a machine; it has also worked for the conversion of nuclear mass into energy in the nuclear fusion and nuclear fission processes.

Heat as a form of energy

ENERGY CONSERVATION AND TRANSFORMATION

The concept of energy conservation. A fundamental law that has been observed to hold for all natural phenomena requires the conservation of energy—*i.e.,* that the total energy does not change in all the many changes that occur in nature. The conservation of energy is not a description of any process going on in nature, but rather it is a statement that the quantity called energy remains constant regardless of when it is evaluated or what processes—possibly including transformations of energy from one form into another—go on between successive evaluations.

The law of conservation of energy is applied not only to nature as a whole but to closed or isolated systems within nature as well. Thus, if the boundaries of a system can be defined in such a way that no energy is either added to or removed from the system, then energy must be conserved within that system regardless of the details of the processes going on inside the system boundaries. A corollary of this closed-system statement is that whenever the energy of a system as determined in two successive evaluations is not the same, the difference is a measure of the quantity of energy that has been either added to or removed from the system in the time interval elapsing between the two evaluations.

Possible forms of energy within a system

Energy can exist in many forms within a system and may be converted from one form to another within the constraint of the conservation law. These different forms include gravitational, kinetic, thermal, elastic, electrical, chemical, radiant, nuclear, and mass energy. It is the universal applicability of the concept of energy, as well as the completeness of the law of its conservation within different forms, that makes it so attractive and useful.

Transformation of energy. *An ideal system.* A simple example of a system in which energy is being converted from one form to another is provided in the tossing of a ball with mass m into the air. When the ball is thrown vertically from the ground, its speed and thus its kinetic energy decreases steadily until it comes to rest momentarily at its highest point. It then reverses itself, and its speed and kinetic energy increase steadily as it returns to the ground. The kinetic energy E_k of the ball at the instant it left the ground (point 1) was half the product of the mass and the square of the velocity, or $\frac{1}{2}mv_1^2$, and decreased steadily to zero at the highest point (point 2). As the ball rose in the air, it gained gravitational potential energy E_p. Potential in this sense does not mean that the energy is not real but rather that it is stored in some latent form and can be drawn upon to do work. Gravitational potential energy is energy that is stored in a body by virtue of its position in the gravitational field. Gravitational potential energy of a mass m is observed to be given by the product of the mass, the height h attained relative to some reference height, and the acceleration g of a body resulting from the Earth's gravity pulling on it, or mgh. At the instant the ball left the ground at height h_1 its potential energy E_{p1} is mgh_1. At its highest point, its potential energy E_{p2} is mgh_2. Applying the law of conservation of energy and assuming no friction in the air, these add up to form the following equations:

Potential and kinetic energy

$$E_{k1} + E_{p1} = E_{k2} + E_{p2}$$

or

$$\frac{1}{2}mv_1^2 + mgh_1 = 0 + mgh_2.$$

In this idealized example the kinetic energy of the ball at ground level is converted into work in raising the ball to h_2 where its gravitational potential energy has been increased by $mg(h_2 - h_1)$. As the ball falls back to the ground level h_1, this gravitational potential energy is converted back into kinetic energy and its total energy at h_1 again is $\frac{1}{2}mv_1^2 + mgh_1$. In this chain of events the kinetic energy of the ball is unchanged at h_1; thus the work done on the ball by the force of gravity acting on it in this cycle of events is zero. This system is said to be a conservative one.

Varying degrees of conversion in real systems. Although the total amount of energy in an isolated system remains unchanged, there may be a great difference in the quality of different forms of energy. Many forms of energy, in theory, can be transformed completely into work or into other forms of energy. This is true for mechanical energy and electrical energy. The random motions of constituent parts of a material associated with thermal energy, however, represent energy that is not available completely for conversion into directed energy.

The French engineer Sadi Carnot described (in 1824) a theoretical power cycle of maximum efficiency for converting thermal into mechanical energy. He demonstrated that this efficiency is determined by the magnitude of the temperatures at which heat energy is added and waste heat is given off during the cycle. A practical engine operating on the Carnot cycle has never been devised, but the Carnot cycle determines the maximum efficiency of thermal energy conversion into any form of directed energy. The Carnot criterion renders 100 percent efficiency impossible for all heat engines. In effect, it constitutes the basis for what is now the second law of thermodynamics.

The so-called Carnot efficiency

(R.L.Se./C.R.R./Ed.)

History of energy-conversion technology

EARLY ATTEMPTS TO HARNESS NATURAL FORMS OF ENERGY

Early humans first made controlled use of an external, nonanimal energy source when they discovered how to use fire. Burning dried plant matter (primarily wood) and animal waste, they employed the energy from this biomass for heating and cooking. The generation of mechanical energy to supplant human or animal power came very much later—only about 2,000 years ago—with the development of simple devices to harness the energy of flowing water and of wind.

Waterwheels. The earliest machines were waterwheels, first used for grinding grain. They were subsequently adopted to drive sawmills and pumps, to provide the bellows action for furnaces and forges, to drive tilt hammers or trip-hammers for forging iron, and to provide direct me-

Diverse applications

chanical power for textile mills. Until the development of steam power during the Industrial Revolution at the end of the 18th century, waterwheels were the primary means of mechanical power production, rivaled only occasionally by windmills. Thus, many industrial towns, especially in early America, sprang up at locations where water flow could be assured all year.

The oldest reference to a water mill dates to about 85 BC, appearing in a poem by an early Greek writer celebrating the liberation from toil of the young women who operated the querns (primitive hand mills) for grinding corn. According to the Greek geographer Strabo, King Mithradates VI of Pontus in Asia used a hydraulic machine, presumably a water mill, by about 65 BC.

Early vertical-shaft water mills drove querns where the wheel, containing radial vanes or paddles and rotating in a horizontal plane, could be lowered into the stream. The vertical shaft was connected through a hole in the stationary grindstone to the upper, or rotating, stone. The device spread rapidly from Greece to other parts of the world, because it was easy to build and maintain and could operate in any fast-flowing stream. It was known in China by the 1st century AD, was used throughout Europe by the end of the 3rd century, and had reached Japan by the year 610. Users learned early that performance could be improved with a millrace and a chute that would direct the water to one side of the wheel.

A horizontal-shaft water mill was first described by the Roman architect and engineer Vitruvius about 27 BC. It consisted of an undershot waterwheel in which water enters below the centre of the wheel and is guided by a millrace and chute. The waterwheel was coupled with a right-angle gear drive to a vertical-shaft grinding wheel. This type of mill became popular throughout the Roman Empire, notably in Gaul, after the advent of Christianity led to the freeing of slaves and the resultant need for an alternative source of power. Early large waterwheels, which measured about 1.8 metres (six feet) in diameter, are estimated to have produced about three horsepower, the largest amount of power produced by any machine of the time. The Roman mills were adopted throughout much of medieval Europe, and waterwheels of increasing size, made almost entirely of wood, were built until the 18th century.

Energy from ocean tides

In addition to flowing stream water, ocean tides were used to drive waterwheels. Tidal water was allowed to flow into large millponds, controlled initially through lock-type gates and later through flap valves. Once the tide ebbed, water was let out through sluice gates and directed onto the wheel. Sometimes the tidal flow was assisted by building a dam across the estuary of a small river. Although limited in operation to ebbing tide conditions, tidal mills were widely used by the 12th century. The earliest recorded reference to tidal mills is found in the *Domesday Book* (1086), which also records more than 5,000 water mills in England south of the Severn and Trent rivers. (Tidal mills also were built along the Atlantic coast in Europe and centuries later on the eastern seaboard of the United States and in Guyana, where they powered sugarcane-crushing mills.)

The first analysis of the performance of waterwheels was published in 1759 by John Smeaton, an English engineer. Smeaton built a test apparatus with a small wheel (its diameter was only 0.61 metre) to measure the effects of water velocity, as well as head and wheel speed. He found that the maximum efficiency (work produced divided by potential energy in the water) he could obtain was 22 percent for an undershot wheel and 63 percent for an overshot wheel (*i.e.*, one in which water enters the wheel above its centre; see Figure 1). In 1776 Smeaton became the first to use a cast-iron wheel, and two years later he introduced cast-iron gearing, thereby bringing to an end the all-wood construction that had prevailed since Roman times. Based on his model tests, Smeaton built an undershot wheel for the London Bridge waterworks that measured 4.6 metres wide and that had a diameter of 9.75 metres. The results of Smeaton's experimental work came to be widely used throughout Europe for designing new wheels.

Influence of Smeaton's work

During the mid-1700s a reaction waterwheel for generating small amounts of power became popular in the rural areas of England. In this type of device, commonly known as a Barker's mill, water flowed into a rotating vertical tube before being discharged through nozzles at the end of two horizontal arms. These directed the water out tangentially, much in the way that a modern rotary lawn sprinkler does. A rope or belt wound around the vertical tube provided the power takeoff.

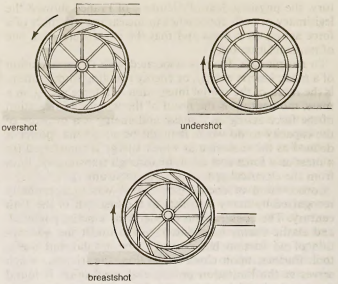

Figure 1: Some major types of waterwheels.

Early in the 19th century Jean-Victor Poncelet, a French mathematician and engineer, designed curved paddles for undershot wheels to allow the water to enter smoothly. His design was based on the idea that water would run up the surface of the curved vanes, come to rest at the inner diameter, and then fall away with practically no velocity. This design increased the efficiency of undershot wheels to 65 percent. At about the same time, William Fairbairn, a Scottish engineer, showed that breast wheels (*i.e.*, those in which water enters at the 10- or two-o'clock position) were more efficient than overshot wheels and less vulnerable to flood damage. He used curved buckets and provided a close-fitting masonry wall to keep the water from flowing out sideways. In 1828 Fairbairn introduced ventilated buckets in which gaps at the bottom of each bucket allowed trapped air to escape. Other improvements included a governor to control the sluice gates and spur gearing for the power takeoff.

During the course of the 19th century, waterwheels were slowly supplanted by water turbines (see *Water turbines* below). Water turbines were more efficient; design improvements eventually made it possible to regulate the speed of the turbines and to run them fast enough to drive electric generators. This fact notwithstanding, waterwheels gave way slowly, and it was not until the early 20th century that they became largely obsolescent. Yet, even today some waterwheels still survive; in the early 1970s there were more than 1,000 grain mills in use in Portugal alone. Equipped with submerged bearings, these modern waterwheels certainly are more sophisticated than their predecessors, though they bear a remarkable likeness to them.

Windmills. Windmills, like waterwheels, were among the original prime movers that replaced animal muscle as a source of power. They were used for centuries in various parts of the world, converting the energy of the wind into mechanical energy for grinding grain, pumping water, and draining lowland areas.

First known wind-powered device

The first known wind device was described by Hero of Alexandria (*c.* 1st century AD). It was modeled on a water-driven paddle wheel and was used to drive a piston pump that forced air through a wind organ to produce sound. The earliest known references to wind-driven grain mills, found in Arabic writings of the 9th century AD, refer to a Persian millwright of AD 644, although windmills may actually have been used earlier. These mills, erected near what is now the Iran–Afghanistan border, had a vertical shaft with paddlelike sails radiating outward and were located in a building with diametrically opposed openings

for the inlet and outlet of the wind. Each mill drove a single set of stones without gearing. The first mills were built with the millstones above the sails, patterned after the early waterwheels from which they were derived. Similar mills were known in China by the 13th century.

Windmills with vertical sails on horizontal shafts reached Europe through contact with the Arabs. Adopting the ideas from contemporary waterwheels, builders began to use fabric-covered, wood-framed sails located above the millstone, instead of a waterwheel below, to drive the grindstone through a set of gears. The whole mill with all its machinery was supported on a fixed post so that it could be rotated and faced into the wind. The millworks were initially covered by a boxlike wooden frame structure and later often by a "round-house," which also provided storage. A brake wheel on the shaft allowed the mill to be stopped by a rim brake. A heavy lever then had to be raised to release the brake, an early example of a fail-safe device. Mills of this sort first appeared in France in 1180, in areas of Syria under the control of the crusaders in 1190, and in England in 1191. The earliest known illustration is from the Windmill Psalter made in Canterbury, Eng., in the second half of the 13th century.

Emergence of the tower mill

The large effort required to turn a post-mill into the wind probably was responsible for the development of the so-called tower mill in France by the early 14th century (see Figure 2). Here, the millstone and the gearing were placed in a massive fixed tower, often circular in section and built of stone or brick. Only an upper cap, normally made of wood and bearing the sails on its shaft, had to be rotated. Such improved mills spread rapidly throughout Europe and later became popular with early American settlers.

The Low Countries of Europe, which had no suitable streams for waterpower, saw the greatest development of windmills. Dutch hollow post-mills, invented in the early 15th century, used a two-step gear drive for drainage pumps. An upright shaft that had gears on the top and bottom passed through the hollow post to drive a paddle-wheel-like scoop to raise water. The first wind-driven sawmill, built in 1592 in the Netherlands by Cornelis Cornelisz, was mounted on a raft to permit easy turning into the wind.

At first both post-mills and the caps of tower mills were turned manually into the wind. Later small posts were placed around the mill to allow winching of the mill with a chain. Eventually winches were placed into the caps of tower mills, engaged with geared racks and operated from inside or from the ground by a chain passing over a wheel. Tower mills had their sail-supporting or tail pole normally inclined at between 5° and 15° to the horizontal. This aided the distribution of the huge sail weight on the tail bearing and also provided greater clearance between the sails and the support structure. Windmills became progressively larger, with sails from about 17 to 24 metres in diameter already common in the 16th century. The material of construction, including all gearing, was wood, although eventually brass or gunmetal came into use for the main bearings. Cast-iron drives were first introduced in 1754 by John Smeaton, the aforementioned English engineer. Little is known about the actual power produced by these mills. In all likelihood only from 10 to 15 horsepower was developed at the grinding wheels. A 50-horsepower mill was not built until the 19th century. The maximum efficiency of large Dutch mills is estimated to have been about 20 percent.

Invention of the fantail

In 1745 Edmund Lee of England invented the fantail, a ring of five to eight vanes mounted behind the sails at right angles to them. These were connected by gears to wheels running on a track around the cap of the mill. As the wind changed direction, it struck the sides of the fantail vanes, realigning them and thereby turning the main sails again squarely into the wind. Fabric-on-wood-frame sails were sometimes replaced by all-wood sails with removable sections. Early sails had a constant angle of twist; variable twist sails resembling a modern airplane propeller were developed much later.

A major problem with all windmills was the need to feather the sails or reduce sail area so that if the wind suddenly increased during a storm the sails would not be ripped apart. In 1772 Andrew Meikle, a Scottish millwright, invented the spring sail, a shutter arrangement similar to a venetian blind in which the sails were controlled by a spring. When the wind pressure exceeded a preset amount, the shutters opened to let some of the wind pass through. In 1789 Stephen Hooper of England introduced roller blinds that could all be simultaneously adjusted with a manual chain from the ground while the mill was working. This was improved upon in 1807 by Sir William Cubitt, who combined Meikle's shutters with Hooper's remote control by hanging varying weights on the adjustment chain, thus making the control automatic. These so-called patent sails, however, found acceptance only in England and northern Europe.

Even though further improvements were made, especially in speed control, the importance of windmills as a major power producer began to decline after 1784, when the first flour mill in England successfully substituted a steam engine for wind power. Yet, the demise of windmills was slow; at one time in the 19th century there were as many as 900 corn (maize) and industrial windmills in the Zaan district of the Netherlands, the highest concentration known. Windmills persisted throughout the 19th century in newly settled or less-industrialized areas, such as the central and western United States, Canada, Australia, and New Zealand. They also were built by the hundreds in the West Indies to crush sugarcane.

Rex Wailes



Figure 2: (Left) Post-mill with four "common sails," the cloths of which are fully set, at Marck, Pas-de-Calais, Fr. (Centre) Hollow post-mill with boarded sails, at Ylojärvi, Häme, Fin. (Right) Tower mill with patent sails and fantail, at Pakenham, Suffolk, Eng.

Use of wind pumps

The primary exception to the steady abandonment of windmills was resurgence in their use in rural areas for pumping water from wells. The first wind pump was introduced in the United States by David Hallay in 1854. After another American, Stewart Perry, began constructing wind pumps made of steel and equipped with metal vanes in 1883, this new and simple device spread around the world.

Wind-driven pumps remain important today in many rural parts of the world. They continued to be used in large numbers, even in the United States, well into the 20th century until low-cost electric power became readily available in rural areas. Although rather inefficient, they are rugged and reliable, need little attention, and remain a prime source for pumping small amounts of water wherever electricity is not economically available. (For the development of the modern wind turbine, see *Wind turbines* below.) (R.W./Fr.L.)

DEVELOPMENTS OF THE INDUSTRIAL REVOLUTION

Steam engines. The rapid growth of industry in Britain from about the mid-18th century (and somewhat later in various other countries) created a need for new sources of motive power, particularly those independent of geographic location and weather conditions. This situation, together with certain other factors, set the stage for the development and widespread use of the steam engine, the first practical device for converting thermal energy to mechanical energy.

Papin's experimental work on steam power

The foundations for the use of steam power are often traced to the experimental work of the French physicist Denis Papin. In 1679 Papin invented a type of pressure cooker, a closed vessel with a tightly fitting lid that confined steam until high pressure was generated. Observing that the steam in the vessel raised the lid, he conceived the idea of using steam to power a piston and cylinder engine.

Thomas Savery, an English inventor and military engineer, studied Papin's work and built a steam-driven suction machine for removing water from coal mines. Savery's machine (patented in 1698) consisted of a boiler, a closed, water-filled reservoir, and a series of valves. Steam was introduced into the reservoir, and the pressure of the steam forced the water out through a one-way outlet valve until the vessel was empty. Water was then sprayed over the surface of the vessel to condense the steam and create a vacuum capable of drawing up more water through a valve below. Unfortunately the vacuum created was not perfect, and so water could only be lifted to a limited height.

Newcomen engine. Some years later another English engineer, Thomas Newcomen, developed a more efficient steam pump consisting of a cylinder fitted with a piston—a design inspired by Papin's aforementioned idea. When the cylinder was filled with steam, a counterweighted pump plunger moved the piston to the extreme upper end of the stroke. With the admission of cooling water, the steam condensed, creating a vacuum. The atmospheric pressure in the mine acted on the piston and caused it to move down in the cylinder, and the pump plunger was lifted by the resulting force (see Figure 3).

Because Savery had obtained a broad patent for his steam device, Newcomen could not patent his engine. He thus entered into a partnership with Savery, and together they built, in 1712, the first piston-operated steam pump.

First piston-operated steam pump

Several years later Smeaton improved the Newcomen engine, almost doubling its efficiency. Although engines of this kind converted only about 1 percent of the thermal energy in the steam to mechanical energy, they remained unrivaled for more than 50 years.

Watt's engine. In 1765 James Watt, a Scottish instrument maker and inventor, modified a Newcomen engine by adding a separate condenser to make it unnecessary to heat and cool the cylinder with each stroke. Because the cylinder and piston remained at steam temperature while the engine was operating, fuel costs dropped by about 75 percent.

Watt entered into a partnership with Matthew Boulton, who owned a factory in Soho, near Birmingham, Eng. At Boulton's insistence he set out to develop a new kind of engine that rotated a shaft instead of providing simple up-and-down motion. He found a way to obtain an inflexible connection between piston and rod (beam) and invented special gear arrangements to convert the up-and-down movement of the beam into circular motion. A heavy flywheel was added to smooth out the variations in the force delivered to the engine shaft by the action of the piston in the cylinder. The flow of steam to the engine was regulated by a governor connected to the flywheel. In addition, Watt applied steam to both sides of the piston to produce greater uniformity of effort and increased power.

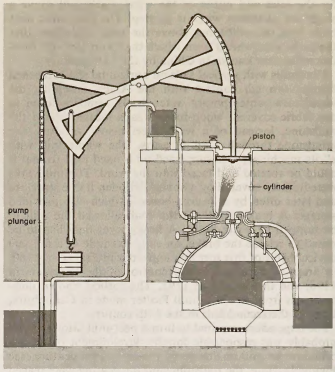

Figure 3: Newcomen engine (see text).

Widespread use of Watt's rotative steam engine

Although far more difficult to build, Watt's rotative engine opened up an entirely new field of application: it enabled the steam engine to be used to operate rotary machines in factories and cotton mills. The rotative engine was widely adopted; it is estimated that by 1800 Watt and Boulton had built 500 engines, of which less than 40 percent were pumps and the rest were of the rotative type.

High-pressure steam engines. Although Watt understood the advantages of utilizing the expansive power of steam within a cylinder, he refused to use steam under high pressure for reasons of safety. This limited the application of steam engines. By the early years of the 19th century, however, the American inventor Oliver Evans had built a stationary high-pressure steam engine for driving a rotary crusher to produce pulverized limestone for agricultural use. Within a few years Evans had designed lighter-weight high-pressure steam engines that could do various other tasks, such as drive sawmills, sow grain, and power a dredge. From 1806 to about 1816 he produced more than 100 steam engines that were employed with screw presses for processing paper, cotton, and tobacco.

Other major advances in the use of high-pressure steam were achieved by Richard Trevithick in England during the early years of the 19th century. Trevithick built the world's first steam-powered railway locomotive in 1803. Two years later he adapted his high-pressure steam engine to drive an iron-rolling mill and to propel a barge with the help of paddle wheels.

First steam locomotive engine

Watt's engine was able to convert only a little more than 2 percent of the thermal energy in steam to work. The improvements introduced by Evans, Trevithick, and others (*e.g.,* three separate expansion cycles and higher steam temperatures) increased the efficiency of the steam engine to roughly 17 percent by 1900. Yet, within the next decade the steam engine was supplanted for various important applications by the more efficient steam turbine (see *Steam turbines* below). Owing to technological advances and the use of high-temperature steam, steam turbines have attained an efficiency of thermal energy conversion of approximately 40 percent. (E.B.Wo./Ed.)

Stirling engine. Many of the early high-pressure steam

External-combustion engine

boilers exploded because of poor materials and faulty methods of construction. The resultant casualties and property losses motivated Robert Stirling of Scotland to invent a power cycle that operated without a high-pressure boiler. In his engine (patented in 1816), air was heated by external combustion through a heat exchanger and then was displaced, compressed, and expanded by two pistons. Stirling also conceived the idea of a regenerator to store thermal energy during part of the cycle and then return this energy to the working fluid. A successful Stirling engine was built for factory use in 1843, but general use was restricted by the high cost of the device. Nevertheless, until about 1920, small engines of this type were used to pump water on farms and to generate electricity for small communities.

Since the Stirling engine is efficient, produces less pollution than most other kinds of engines, and operates on virtually any kind of fuel, efforts have been made intermittently since the late 1930s to reduce its manufacturing costs. Modern versions of the Stirling engine employ pressurized hydrogen or helium instead of air. Although attempts were made as recently as the 1970s to adapt the device to power automobiles, its only commercial application at present is use as a cryogenic refrigerator.

Internal-combustion engines. While the steam engine remained dominant in industry and transportation during much of the 19th century, engineers and scientists began developing other sources and converters of energy. One of the most important of these was the internal-combustion engine. In such a device a fuel and oxidizer are burned within the engine and the products of combustion act directly on piston or rotor surfaces. By contrast, an external-combustion device, such as the steam engine, employs a secondary working fluid that is interposed between the combustion chamber and power-producing elements. By the early 1900s the internal-combustion engine had replaced the steam engine as the most broadly applied power-generating system not only because of its higher thermal efficiency (there is no transfer of heat from combustion gases to a secondary working fluid that results in losses in efficiency) but also because it provided a low-weight, reasonably compact, self-contained power plant.

First practical internal-combustion engine

The German engineer Nikolaus August Otto is generally credited with having built the first practical internal-combustion engine (1876), though several rudimentary devices had appeared earlier in the century. In 1885 Gottlieb Daimler, another German engineer, modified the four-cycle Otto engine so that it burned gasoline (instead of coal powder) and built the first successful high-speed internal-combustion engine. Within several decades the gasoline engine found wide application in motorcycles, automobiles, and small trucks (see *Gasoline engines* below).

Another type of internal-combustion engine was introduced by Rudolf Diesel, also of Germany, in the early 1890s. Named for its inventor, the diesel engine was more efficient than engines of the Otto variety and was fueled by heavy oil, which is cheaper and less volatile than gasoline. As a result, it was adopted as the primary power plant for submarines, railway locomotives, and heavy machinery (see *Diesel engines* below).

An internal-combustion engine quite different from the reciprocating piston type was developed around the turn of the century. This was the gas-turbine engine, the first successful version of which was built in 1903 in France. Modern gas turbines have been used for electric power generation and various other purposes, but its primary application has been jet propulsion. In a gas-turbine system compressed air, heated by the combustion of petroleum, is used to turn a turbine to drive the compressor while excess energy accelerates the exhaust gas to high velocity for producing thrust (see *Gas-turbine engines* and *Jet engines* below).

Early studies of rocket propulsion systems

Another form of propulsive engine, the rocket, attracted increasing attention during the final decades of the 19th century due in part to the imaginative portrayals of space travel fabricated by Jules Verne and other science-fiction writers. From about 1880, various scientists and inventors began investigating theoretical problems of rocket motion and propulsion system design. By the mid-1920s Robert H. Goddard of the United States had developed experimental rockets employing liquid and solid propellants (see *Rockets* below).

Electric generators and motors. Other important energy-conversion devices emerged during the 19th century. During the early 1830s the English physicist and chemist Michael Faraday discovered a means by which to convert mechanical energy into electricity on a large scale. While engaged in experimental work on magnetism, Faraday found that moving a permanent magnet into and out of a coil of wire induced an electric current in the wire. This process, called electromagnetic induction, provided the working principle for electric generators.

The Gramme dynamo

During the late 1860s Zénobe-Théophile Gramme, a French engineer and inventor, built a continuous-current generator. Dubbed the Gramme dynamo, this device contributed much to the general acceptance of electric power. By the early 1870s Gramme had developed several other dynamos, one of which was reversible and could be used as an electric motor. Electric motors, which convert electrical energy to mechanical energy, run virtually every kind of machine that uses electricity.

All of Gramme's machines were direct-current (DC) devices. It was not until 1888 that Nikola Tesla, a Serbian-American inventor, introduced the prototype of the present-day alternating-current (AC) motor (see *Electric generators and electric motors* below).

Direct energy-conversion devices. Most of these energy converters, sometimes called static energy-conversion devices, use electrons as their "working fluid" in place of the vapour or gas employed by such dynamic heat engines as the external-combustion and internal-combustion engines mentioned above. In recent years, direct energy-conversion devices have received much attention because of the necessity to develop more efficient ways of transforming available forms of primary energy into electric power. Four such devices—the electric battery, the fuel cell, the thermoelectric generator (or at least its working principle), and the solar cell—had their origins in the early 1800s.

Electrochemical generation of electricity

The battery, invented by the Italian physicist Alessandro Volta about 1800, changes chemical energy directly into an electric current. A device of this type has two electrodes, each of which is made of a different chemical. As chemical reactions occur, electrons are released on the negative electrode and made to flow through an external circuit to the positive electrode. The process continues until the circuit is interrupted or one of the reactants is exhausted. The forerunners of the modern dry cell and the lead-acid storage battery appeared during the second half of the 19th century (see *Batteries* below).

The fuel cell, another electrochemical producer of electricity, was developed by William Robert Grove, a British physicist, in 1839. In a fuel cell, continuous operation is achieved by feeding fuel (*e.g.*, hydrogen) and an oxidizer (oxygen) to the cell and removing the reaction products (see *Fuel cells* below).

Thermoelectricity

Thermoelectric generators are devices that convert heat directly into electricity. Electric current is generated when electrons are driven by thermal energy across a potential difference at the junction of two conductors made of dissimilar materials. This effect was discovered by Thomas Johann Seebeck, a German physicist, in 1821. Seebeck observed that a compass needle near a circuit made of different conducting materials was deflected when one of the junctions was heated. He investigated various materials that produce electric energy with an efficiency of 3 percent. This efficiency was comparable to that of the steam engines of the day. Yet, the significance of the discovery of the thermoelectric effect went unrecognized as a means of producing electricity because of Seebeck's misinterpretation of the phenomenon as a magnetic effect caused by a difference in temperature. A basic theory of thermoelectricity was finally formulated during the early 1900s, though no functional generators were developed until much later (see *Thermoelectric power generators* below).

Conversion of solar energy into electric power

In a solar cell, radiant energy drives electrons across a potential difference at a semiconductor junction in which the concentrations of impurities are different on the two sides of the junction. What is often considered the first

genuine solar cell was built in the late 1800s by Charles Fritts, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold (see *Exploiting renewable energy sources* below).

MODERN DEVELOPMENTS

The 20th century brought a host of important scientific discoveries and technological advances, including new and better materials and improved methods of fabrication. These developments permitted the enhancement and refinement of many of the energy-conversion devices and systems that had been introduced during the previous century, as exemplified by the remarkable evolution of jet engines and rockets. They also gave rise to entirely new technologies.

Discovery and application of nuclear energy. *Fission reactors.* Scientists first learned of the tremendous energy bound in the nucleus of the atom during the early years of the century. In 1942 they succeeded in unleashing that energy on a large scale by means of what was called an atomic pile. This was the first nuclear fission reactor, a device designed to induce a self-sustaining and controlled series of fission reactions that split heavy nuclei to release their energy. It was built for the U.S. Manhattan Project undertaken to develop the atomic bomb. Shortly after World War II, reactors were built for submarine propulsion and for commercial power production. The first full-scale commercial nuclear power plant was opened in 1956 at Calder Hall, Eng. In a power generation system of this kind, much of the energy released by the fissioning of heavy nuclei (principally those of the radioactive isotope uranium-235) takes the form of heat, which is used to produce steam. This steam drives a turbine, the mechanical energy of which is converted to electricity by a generator (see *Nuclear fission reactors* below).

First nuclear reactor

Fusion reactors. In the late 1930s Hans A. Bethe, a German-born physicist, recognized that the fusion of hydrogen nuclei to form deuterium releases energy. Since that time scientists have sought to harness such thermonuclear reactions for practical energy production. Much of their work has centred on the use of magnetic fields and electromagnetic forces to confine plasma, an exceedingly hot gas composed of unbound electrons, ions, and neutral atoms and molecules. Plasma is the only state of matter in which thermonuclear reactions can be induced and sustained to generate usable amounts of thermal energy. The difficulty is in confining plasma long enough for this to happen. Although researchers have made significant headway toward constructing fusion reactors capable of such confinement, no device of this kind has been developed sufficiently for commercial application (see *Fusion reactors* below).

Other conversion technologies. Energy requirements for space vehicles led to an intensive investigation, from 1955 on, of all possible energy sources. Direct energy-conversion devices are of interest for providing electric power in spacecraft because of their reliability and their lack of moving parts. As have solar cells, fuel cells, and thermoelectric generators, thermionic power converters have received considerable attention for space applications. Thermionic generators are designed to convert thermal energy directly into electricity. The required heat energy may be supplied by chemical, solar, or nuclear sources, the latter being the preferred choice for current experimental units (see *Thermionic power converters* below).

Research associated with the space program

Another direct energy converter with considerable potential is the magnetohydrodynamic (MHD) power generator. This system produces electricity directly from a high-temperature, high-pressure electrically conductive fluid—usually an ionized gas—moving through a strong magnetic field. The hot fluid may be derived from the combustion of coal or other fossil fuel. The first successful MHD generator was built and tested during the 1950s. Since that time developmental efforts have progressed steadily, culminating in a Russian project to build an MHD power plant in the city of Ryazan, located about 180 kilometres (112 miles) southeast of Moscow (see *Magnetohydrodynamic power generators* below).

Exploiting renewable energy sources. Growing concern over the world's ever-increasing energy needs and the prospect of rapidly dwindling reserves of oil, natural gas, and uranium fuel have prompted efforts to develop viable alternative energy sources. The volatility and uncertainty of the petroleum fuel supply were dramatically brought to the fore during the energy crisis of the 1970s caused by the abrupt curtailment of oil shipments from the Middle East to many of the highly industrialized nations of the world. It also has been recognized that the heavy reliance on fossil fuels has had an adverse impact on the environment. Gasoline engines and steam-turbine power plants that burn coal or natural gas emit substantial amounts of sulfur dioxide and nitrogen oxides into the atmosphere. When these gases combine with atmospheric water vapour, they form sulfuric acid and nitric acids, giving rise to highly acidic precipitation. The combustion of fossil fuels also releases carbon dioxide. The amount of this gas in the atmosphere has steadily risen since the mid-1800s largely as a result of the growing consumption of coal, oil, and natural gas. More and more scientists believe that the atmospheric buildup of carbon dioxide (along with that of other industrial gases such as methane and chlorofluorocarbons) may induce a greenhouse effect, raising the surface temperature of the Earth by increasing the amount of heat trapped in the lower atmosphere. This condition could bring about climatic changes with serious repercussions for natural and agricultural ecosystems. (For a detailed discussion of acid rain and the greenhouse effect, see the articles ATMOSPHERE: *Effects of human activity on atmospheric composition and their ramifications* and HYDROSPHERE, THE: *Acid rain* and *Buildup of greenhouse gases.*)

Depletion of fuel resources and environmental pollution

Many countries have initiated programs to develop renewable energy technologies that would enable them to reduce fossil-fuel consumption and its attendant problems. Fusion devices are believed to be the best long-term option, since their primary energy source would be the hydrogen isotope deuterium abundantly present in ordinary water. Other technologies that are being actively pursued are those designed to make wider and more efficient use of the energy in sunlight, wind, moving water, and terrestrial heat (*i.e.,* geothermal energy). The amount of energy in such renewable and virtually pollution-free sources is large in relation to world energy needs, yet at the present time only a small portion of it can be converted to electric power at reasonable cost.

A variety of devices and systems has been created to better tap the energy in sunlight. Among the most efficient are photovoltaic systems that transform radiant energy from the Sun directly into electricity by means of silicon or gallium arsenide solar cells. Large arrays consisting of thousands of these semiconductor cells can function as central power stations (see *Solar cells* below). Other systems, which are still under development, are designed to concentrate solar radiation not only to generate electric power but also to produce high-temperature process heat for various applications. These systems employ a number of different components, including large parabolic concentrators and heat engines of the Stirling engine type (see above). Another approach involves the use of flat-plate solar collectors to provide space heating for commercial and residential buildings.

Although wind is intermittent and diffuse, it contains tremendous amounts of energy. Sophisticated wind turbines have been developed to convert this energy to electric power. The utilization of wind energy systems grew discernibly during the 1980s. For example, more than 15,000 wind turbines are now in operation in Hawaii and California at specially selected sites. Their combined power rating of 1,500 megawatts is roughly equal to that of a conventional steam-turbine power installation (see *Wind turbines* below).

Wind power

Converting the energy in moving water to electricity has been a long-standing technology. Yet, hydroelectric power plants are estimated to provide only about 2 percent of the world's energy requirements. The technology involved is simple enough: hydraulic turbines change the energy of fast-flowing or falling water into mechanical energy that drives power generators, which produce electricity

(see *Water turbines* below). Hydroelectric power plants, however, generally require the building of costly dams. Another factor that limits any significant increase in hydroelectric power production is the scarcity of suitable sites for additional installations except in certain regions of the world.

In certain coastal areas of the world, as, for example, the Rance River estuary in Brittany, Fr., hydraulic turbine-generator units have been used to harness the great amount of energy in ocean tides (see *Tidal plants* below). At most such sites, the capital costs of constructing damlike structures with which to trap and store water are prohibitive, however.

Geothermal energy flows from the hot interior of the Earth to the surface in steam or hot water most often in areas of active volcanism. Geothermal reservoirs with temperatures of 180° C or higher are suitable for power generation. The earliest commercial geothermal power plant was built in 1904 in Larderello, Italy. Today, steam from wells drilled to depths of hundreds of metres drives the plant's turbine generators to produce about 190 megawatts of electricity. Geothermal plants have been built in a number of other countries, including El Salvador, Japan, Mexico, New Zealand, and the United States. The principal U.S. plant, located at The Geysers north of San Francisco, can generate up to 1,900 megawatts, though production may be restricted to prolong the life of the steam field. (C.R.R./Ed.)

First commercial geothermal power plant

MAJOR ENERGY-CONVERSION DEVICES AND SYSTEMS

Turbines

A turbine is a machine that converts the energy stored in a fluid into mechanical energy. This conversion is generally accomplished by passing the fluid through a system of stationary passages or vanes that alternate with passages consisting of finlike blades attached to a rotor. By arranging the flow so that a tangential force, or torque, is exerted on the rotor blades, the rotor will turn, and work can be extracted. Turbines can be classified into four general types according to the fluids used: water, steam, gas, and wind. Although the same principles apply to all turbines, their specific designs differ sufficiently to merit separate descriptions.

Classification of turbines

A water turbine uses the potential energy resulting from the difference in elevation between an upstream water reservoir and the turbine-exit water level (the tailrace) to convert this so-called head into work. Water turbines are the modern successors of simple waterwheels, which date back about 2,000 years (see *Waterwheels* above). Today, the primary use of water turbines is for electric power generation.

The greatest amount of electrical energy comes, however, from steam turbines coupled to electric generators. The turbines are driven by steam produced in either a fossil-fuel-fired or a nuclear-powered generator. The energy that can be extracted from the steam is conveniently expressed in terms of the enthalpy change across the turbine. Enthalpy reflects both thermal and mechanical energy forms in a flow process and is given by the sum of the internal thermal energy and the product of pressure times volume. The available enthalpy change through a steam turbine increases with the temperature and pressure of the steam generator and with reduced turbine-exit pressure.

For gas turbines, the energy extracted from the fluid also can be expressed in terms of the enthalpy change, which for a gas is nearly proportional to the temperature drop across the turbine. In gas turbines the working fluid is air mixed with the gaseous products of combustion. Most gas-turbine engines include at least a compressor, a combustion chamber, and a turbine. These are usually mounted as an integral unit and operate as a complete prime mover on a so-called open cycle where air is drawn in from the atmosphere and the products of combustion are finally discharged again to the atmosphere. Since successful operation depends on the integration of all components, it is important to consider the whole device, which is actually an internal-combustion engine, rather than the turbine alone. For this reason, gas turbines will be treated in the section *Internal-combustion engines*.

The energy available in wind can be extracted by a wind turbine to produce electric power or to pump water from wells. Wind turbines are the successors of windmills, which were important sources of power from the late Middle Ages through the 19th century (see *Windmills* above). (Fr.L.)

WATER TURBINES

Principal types

Water turbines are generally divided into two categories: (1) impulse turbines used for high heads of water and low flow rates and (2) reaction turbines normally employed for heads below about 450 metres and moderate or high flow rates. These two classes include the main types in common use—namely, the Pelton impulse turbine and the reaction turbines of the Francis, propeller, Kaplan, and Deriaz variety. Turbines can be arranged with either horizontal or, more commonly, vertical shafts. Wide design variations are possible within each type to meet the specific local hydraulic conditions. Today, most hydraulic turbines are used for generating electricity in hydroelectric installations.

Impulse turbines. In an impulse turbine the potential energy, or the head of water, is first converted into kinetic energy by discharging water through a carefully shaped nozzle. The jet, discharged into air, is directed onto curved buckets fixed on the periphery of the runner to extract the water energy and convert it to useful work.

Modern impulse turbines are based on a design patented in 1889 by the American engineer Lester Allen Pelton. The free water jet strikes the turbine buckets tangentially. Each bucket has a high centre ridge so that the flow is divided to leave the runner at both sides. Pelton wheels are suitable for high heads, typically above about 450 metres with relatively low water flow rates. For maximum efficiency the runner tip speed should equal about one-half the striking jet velocity. The efficiency (work produced by the turbine divided by the kinetic energy of the free jet) can exceed 91 percent when operating at 60–80 percent of full load.

Pelton turbines

The power of a given wheel can be increased by using more than one jet. Two-jet arrangements are common for horizontal shafts (see Figure 4). Sometimes two separate runners are mounted on one shaft driving a single electric generator. Vertical-shaft units may have four or more separate jets.

If the electric load on the turbine changes, its power output must be rapidly adjusted to match the demand. This

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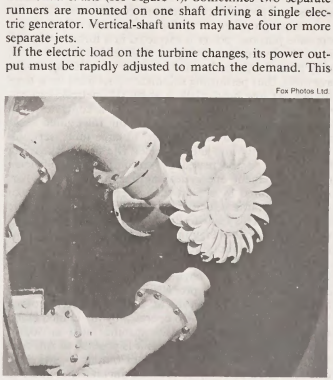

Figure 4: Pelton water turbine with twin jets.

requires a change in the water flow rate to keep the generator speed constant. The flow rate through each nozzle is controlled by a centrally located, carefully shaped spear or needle that slides forward or backward as controlled by a hydraulic servomotor.

Proper needle design assures that the velocity of the water leaving the nozzle remains essentially the same irrespective of the opening, assuring nearly constant efficiencies over much of the operating range. It is not prudent to reduce the water flow suddenly to match a load decrease. This could lead to a destructive pressure surge (water hammer) in the supply pipeline, or penstock. Such surges can be avoided by adding a temporary spill nozzle that opens while the main nozzle closes or, more commonly, by partially inserting a deflector plate between the jet and the wheel, diverting and dissipating some of the energy while the needle is slowly closed.

Turgo impulse turbines

Another type of impulse turbine is the turgo type. The jet impinges at an oblique angle on the runner from one side and continues in a single path, discharging at the other side of the runner. This type of turbine has been used in medium-sized units for moderately high heads.

Reaction turbines. In a reaction turbine, forces driving the rotor are achieved by the reaction of an accelerating water flow in the runner while the pressure drops. The reaction principle can be observed in a rotary lawn sprinkler where the emerging jet drives the rotor in the opposite direction. Due to the great variety of possible runner designs, reaction turbines can be used over a much larger range of heads and flow rates than impulse turbines. Reaction turbines typically have a spiral inlet casing that includes control gates to regulate the water flow. In the inlet a fraction of the potential energy of the water may be converted to kinetic energy as the flow accelerates. The water energy is subsequently extracted in the rotor.

There are, as noted above, four major kinds of reaction turbines in wide use: the Kaplan, Francis, Deriaz, and propeller type. In fixed-blade propeller and adjustable-blade Kaplan turbines (named after the Austrian inventor Victor Kaplan), there is essentially an axial flow through the machine. The Francis- and Deriaz-type turbines (after the British-born American inventor James B. Francis and the Swiss engineer Paul Deriaz, respectively) use a "mixed flow," where the water enters radially inward and discharges axially. Runner blades on Francis and propeller turbines consist of fixed blading, while in Kaplan and Deriaz turbines the blades can be rotated about their axis, which is at right angles to the main shaft.

Propeller-type turbines

Axial-flow machines. Fixed propeller-type turbines are generally used for large units at low heads, resulting in large diameters and slow rotational speeds. As the name suggests, a propeller-type turbine runner looks like the very large propeller of a ship except that it serves the opposite purpose: power is extracted in a turbine, whereas it is fed into a marine propeller. The central shaft, or hub, may have the propeller blades bolted to it during on-site assembly, thus permitting shipment by sections for a large runner. At low heads (below about 24 metres), vertical-shaft propeller turbines typically have a concrete spiral inlet casing of rectangular cross section. Inlet guide vanes are either mounted on a ring or, in large units, set individually directly into the concrete. The flow passage can be increased or decreased by servomotor-driven wicket gates. The kinetic energy leaving the runner can be partially recaptured by a draft tube, a conical diffusing exit section where the velocity is decreased while the pressure is increased. This leads to improved efficiency by keeping the loss of kinetic energy in the exit, or tail, section of the installation to a minimum.

Propeller turbines are used extensively in North America, where low heads and large flow rates are common. For example, there are 32 propeller turbines in the Moses–Saunders Power Dam on the St. Lawrence River between New York and Ontario—16 operated by the United States and 16 by Canada, with each turbine rated at 50,000 kilowatts. With such large plants it is possible to run each turbine at or near its most efficient output by switching complete units in or out as the load fluctuates, in addition to regulating each unit.

If the head or the water flow rate tends to vary seasonally, as occurs in many river systems, an installation with only a few propeller turbines might have to operate all units at partial output under average flow and load conditions. The energy-conversion efficiency of a conventional propeller turbine decreases rapidly once the turbine load drops below 75 percent of its rating. This performance loss can be minimized by varying the inlet-blade angle of the runner to match the runner-inlet conditions more accurately with the water velocity for a given flow. In such a Kaplan turbine (Figure 5) each blade can be swiveled about a post at right angles to the main turbine shaft, thus producing a variable pitch. The angle of the blades is controlled by an oil-pressure operated servomotor, usually mounted in the rotor hub with the oil fed through the generator and turbine shaft. The servo-control system, which also drives the gates through a cam or rocker arrangement, is designed to adjust angles and inlet flows to match the electrical load while keeping the main shaft with its directly coupled generator rotating at constant speed. Runners with four to six blades are common, though more blades may be used for high heads. British manufacturers have developed Kaplan designs for heads up to 58 metres.

Kaplan turbines

By courtesy of The English Electric Co. Ltd.

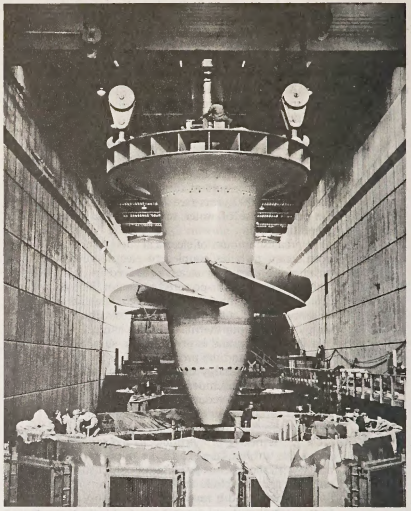

Figure 5: A 131,000-horsepower Kaplan water-turbine runner.

Although the usual turbine installation has a vertical shaft, some also have been designed with horizontal shafts. In a horizontal bulb arrangement, the generator is embedded in a nacelle, corresponding to the thick body of a light bulb, while the blades are set around a hub corresponding to the thinner bulb socket. This design is suitable for medium-sized machines operating at very low heads when an almost straight-through water flow is desirable. The Rance River tidal plant in France employs this kind of arrangement (see *Tidal plants* below).

Francis turbines

Mixed-flow turbines. Francis turbines are probably used most extensively because of their wider range of suitable heads, characteristically from three to 600 metres. At the high-head range, the flow rate and the output must be large; otherwise the runner becomes too small for reasonable fabrication. At the low-head end, propeller turbines are usually more efficient unless the power output is also

small. Francis turbines reign supreme in the medium-head range of 120 to 300 metres and come in a wide range of designs and sizes. They can have either horizontal or vertical shafts, the latter being used for machines with diameters of about two metres or more. Vertical-shaft machines usually occupy less space than horizontal units, permit greater submergence of the runner with a minimum of deep excavation, and make the tip-mounted generator more easily accessible for maintenance. Horizontal-shaft units are more compact for smaller sizes and allow easier access to the turbine, although removal of the generator for repair becomes more difficult as size increases.

The most common form of Francis turbine has a welded, or cast-steel, spiral casing. The casing distributes water evenly to all inlet gates; up to 24 pivoted gates or guide vanes have been used. The gates operate from fully closed to wide open, depending on the power output desired. Most are driven by a common regulating speed ring and are pin-connected in such a fashion that no damage will occur if debris blocks one of the gate passages. The regulating ring is rotated by one or two oil-pressure servomotors that are controlled by the speed governor.

Slow, high-power units have a nearly radial set of blades, while in fast and lower-powered units the curved blades reach from the radial inlet to almost the axial outlet (see Figure 6). Once the overall blade dimensions (inlet and exit diameters and blade height) have been defined, the blades are designed for a smooth entry of the water flow at the inlet and minimum water swirl at the exit. The number of blades can vary from seven to 19. Runners for low-head units are usually made of cast mild steel, sometimes with stainless-steel protection added at locations subject to cavitation (see below). All stainless-steel construction is more commonly used for high heads. Large units can be welded together on-site, using an appropriate combination of various preformed steel sections to provide carefully shaped, finished water passages. Francis turbines allow for very large, high-output units. The Grand Coulee hydroelectric power plant on the Columbia River in Washington state has the largest single runner in the United States, a device capable of producing 716,000 kilowatts at a head of 93 metres. The world's largest hydroelectric power installation, the Itaipú plant on the Paraná River between Brazil and Paraguay, is scheduled to have 18 Francis turbines capable of producing 740,000 kilowatts each at heads between 118.4 and 126.7 metres while rotating at slightly above 90 revolutions per minute (rpm).

By courtesy of Voith Hydro, Inc.



Figure 6: A Francis water-turbine runner.

Deriaz-type mixed-flow turbine

A mixed-flow turbine of the Deriaz type uses swiveled, variable-pitch runner blades that allow for improved efficiency at part loads in medium-sized machines (see Figure 7). The Deriaz design has proved useful for higher heads and also for some pumped storage applications (see below). It has the advantage of a lower runaway (sudden loss of load) speed than a Kaplan turbine, which results in significant savings in generator costs. Very few Deriaz turbines, however, have actually been built. The first non-reversible Deriaz turbine, capable of producing 22,750 kilowatts with a head of 55 metres, was installed in an underground station at Culligran, Scot., in 1958.

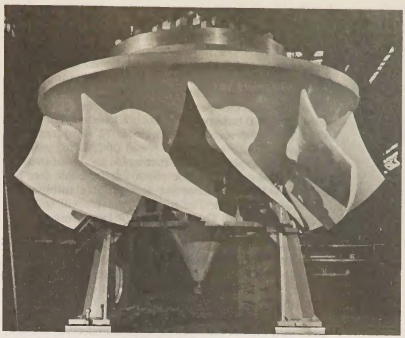

Figure 7: Runner for 108,000-horsepower Deriaz reversible pump turbine for Valdecañas Power Station, Spain.
By courtesy of The English Electric Co. Ltd.

Other design considerations. *Output and speed control.* If the load on the generator is decreased, a turbine will tend to speed up unless the flow rate can be reduced accordingly. Similarly, an increase of load will cause the turbine to slow down unless more water can be admitted. Since electric-generator speeds must be kept constant to a high degree of precision, this leads to complex controls. These must take into account the large masses and inertias of the metal and the flowing water, including the water in the inflow pipes (or penstocks), that will be affected by any change in the wicket gate setting. If the inlet pipeline is long, the closing time of the wicket gate must be slow enough to keep the pressure increase caused by a reduction in flow velocity within acceptable limits. If the closing or opening rate is too slow, control instabilities may result. To assist regulation with long pipelines, a surge chamber is often connected to the pipeline as close to the turbine as possible. This enables part of the water in the line to pass into the surge chamber when the wicket gates are rapidly closed or opened. Medium-sized reaction turbines may also be provided with pressure-relief valves through which some water can be bypassed automatically as the governor starts to close the turbine. In some applications, both relief valves and surge chambers have been used.

Cavitation. According to Bernoulli's principle (derived by the Swiss mathematician Daniel Bernoulli), as the flow velocity of the water increases at any given elevation, the pressure will drop. There is a danger that in high-velocity sections of a reaction turbine, especially near the exit, the pressure can become so low that the water flashes over into small vapour bubbles, which then collapse suddenly. This so-called cavitation leads to erosion pitting as well as to vibrations and must be avoided by the careful shaping of all blade passages and of the exit passage or draft tube.

Problems associated with cavitation

Turbine selection on the basis of specific speed. Initial turbine selection is usually based on the ratio of design variables known as the power specific speed. In U.S. design practice this is given by

$$N = \frac{nP^{1/2}}{H^{5/4}},$$

where n is in revolutions per minute, P is the output in horsepower, and H is the head of water in feet. Turbine types can be classified by their specific speed, N, which always applies at the point of maximum efficiency. If N ranges from one to 20, corresponding to high heads and

low rotational speeds, impulse turbines are appropriate. For N between 10 and 90, Francis-type runners should be selected, with slow-running, near-radial units for the lower N values and more rapidly rotating mixed-flow runners for higher N values. For N up to 110, Deriaz turbines may be suitable. If N ranges from 70 to the maximum of 260, propeller or Kaplan turbines are called for.

Using the specific speed formula, a turbine designed to deliver 100,000 horsepower (74,600 kilowatts) with a head of 40 feet (12.2 metres) operating at 72 revolutions per minute would have a specific speed of 226, suggesting a propeller or Kaplan turbine. It can also be shown that the flow rate would have to be about 24,500 cubic feet per second (694 cubic metres per second) at a turbine efficiency of 90 percent. The runner diameter will be about 33 feet (10 metres). This illustrates the large sizes required for high-power, low-head installations and the low rotational speed at which these turbines have to operate to stay within the permissible specific speed range.

Turbine model testing. Before building large-scale installations, the design should be checked out with turbine model tests, using geometrically similar models of small and intermediate size, all operating at the same specific speed. Allowances must be made for the effects of friction, determined by the Reynolds number (density × rotational speed × runner diameter squared/viscosity) and for possible changes in scaled roughness and clearance dimensions. Friction effects are less important for large units, which tend to be more efficient than smaller ones.

Applications. *Electric power generation.* Water turbines are used almost exclusively for generating electric power that can be transmitted through high-voltage power lines to population centres. The United States and Canada are among the leaders in hydroelectric power production, though many other countries also have major production facilities. Until the late 1950s most single turbogenerator units had capacities of less than 150,000 kilowatts. By the late 1980s construction costs and the need for reliability pointed toward 250,000- to 300,000-kilowatt units, although some recent installations were equipped with turbines capable of up to 750,000 kilowatts.

Pumped storage. Electricity must be used as soon as it is generated; there are no economical means of storing large quantities of electric energy. Thus hydroelectric plants built for near-maximum power consumption during daytime peak hours would have to operate at low efficiency during nighttime or weekend off-hours. To avoid this, water can be pumped to a second, higher reservoir during off-hours for storage in the form of potential energy and then fed back through power-generating turbines at times of high demand. Even though this system does not generate new energy (there actually is a reduction in energy due to losses involved in pump and turbine operation as well as in the electric motor and generator), pumped hydro-storage often becomes economical when compared with the cost of constructing additional turbines for peak power demands.

Use of reversible-pump turbines

Modern pumped storage units in the United States normally use reversible-pump turbines that can be run in one direction as pumps and in the other direction as turbines. These are coupled to reversible electric motor/generators. The motor drives the pump during the storage portion of the cycle, while the generator produces electricity during discharge from the upper reservoir.

Most reversible-pump turbines are of the Francis type. The complexity of the unit, however, increases significantly as compared to a turbine alone. In spite of the higher costs for both hydraulic and electrical controls and support equipment, the total installed cost will be less than for completely separate pump-motor and turbine-generator assemblies with dual water passages.

Some very economical pumped storage plants have heads exceeding 300 metres. In the past this was considered too high for single-stage pumps, and the use of separate multistage, nonreversible units was required. Satisfactory reversible single-stage pump turbines, however, have been developed that can operate at 700-metre heads, though most installations have smaller head differences between the upper and lower reservoirs.

For medium heads, Deriaz turbines have had some success because they allow ready adjustment of the runner-blade angles to match the opposite requirements of pumping and power generation. The pumping load can also be varied with Deriaz-type units, which cannot be done with a Francis runner. A further advantage of a Deriaz-type machine is that the runner blades can be closed to form a smooth cone, a feature that permits pump start-up with minimum load while the unit is submerged in water.

An early major Deriaz reversible-pump turbine system was installed at plants on both the Canadian and U.S. sides of Niagara Falls; this made it possible to provide "side storage" at night without impairing the tourist attraction of the falls by reducing the flow during the day. The Tuscarora plant on the U.S. side uses 12 pump turbines at heads between 18.3 to 29 metres.

Pumped storage has become widespread in industrialized nations. In the United States alone more than 30 pumped hydropower stations were in operation by the mid-1980s. The largest plant is located in Bath County, Va., where six pump-turbines have a total capacity of 2.1 million kilowatts. This amount of power can be generated over an 11-hour period.

Tidal plants. Although the majority of hydroelectric plants depend on the impoundment of rivers, tidal power still could play a role, albeit minor, in electric power generation during the coming years. Areas where the normal tide runs high, such as in the Bay of Fundy between the United States and Canada or along the English Channel, can allow water to flow into a dam-controlled basin during high tide and discharge it during low tide to produce intermittent power. One such plant is located in France on the estuary of the Rance River near Saint-Malo in Brittany. There, a reservoir has been created by a barrage four kilometres inland from the river mouth to make use of tides ranging from about 3.4 to 13.4 metres. The power station is equipped with 24 reversible bulb-type propeller turbines coupled to reversible motor/generators, each having a capacity of 10,000 kilowatts. Pumped storage is used if the tidal outflow through the plant falls below peak power demands. A pilot tidal plant with a 40,000-kilowatt capacity has been built in Russia on the Barents Sea. If this facility proves economical, it may lead to the construction of other tidal plants on the northern and eastern Russian coasts.

Rance River tidal plant

Cost of hydroelectric power. Although large hydroelectric plants can be operated economically, the cost of land acquisition and of dam and reservoir construction must be included in the total cost of power, since these outlays generally account for about half of the total initial cost. Most large plants serve multiple purposes: hydropower generation, flood control, storage of drinking water, and the impounding of water for irrigation. If the construction costs are properly prorated to the non-power-producing utility of the unit, electricity can be sold very cheaply. In the Pacific Northwest region of the United States, such accounting has given hydroelectric plants an apparent cost advantage over fossil-fueled units.

History of water turbine technology. Experiments on the mechanics of reaction wheels conducted by the Swiss mathematician Leonhard Euler and his son Albert in the 1750s found application about 75 years later. In 1826 Jean-Victor Poncelet of France proposed the idea of an inward-flowing radial turbine, the direct precursor of the modern water turbine. This machine had a vertical spindle and a runner with curved blades that was fully enclosed. Water entered radially inward and discharged downward below the spindle.

Precursor of the modern water turbine

A similar machine was patented in 1838 by Samuel B. Howd of the United States and built subsequently. Howd's design was improved on by James B. Francis, who added stationary guide vanes and shaped the blades so that water could enter shock-free at the correct angle. His runner design, which came to be known as the Francis turbine (see above), is still the most widely used for medium-high heads. Improved control was proposed by James Thomson, a Scottish engineer, who added coupled and pivoted curved guide vanes to assure proper flow directions even at part load.

A radial outward-flow turbine had been proposed in 1824 by the French engineering professor Claude Burdin and his former student Benoît Fourneyron. This device had a vertical axis carrying a runner with curved blades through which the water left almost tangentially. Fixed guide vanes, curved in the opposite direction, were mounted in an annulus inside the runner. Unfortunately the design made it difficult to support the runner and to take power off the turbine wheel. The first successful version of the turbine was built by Fourneyron in 1827. More than 100 such machines were subsequently built all over the world; they achieved efficiencies up to 75 percent at full load with heads up to 107 metres. In 1844 Uriah A. Boyden added an outlet diffuser to recover part of the kinetic energy exiting the device and thereby further improved efficiency. Outward-flow turbines, however, are inherently unstable, and speed control is difficult. Moreover, the construction of outward-flow turbines is very complex as compared to that of Francis-type runners, and this fact led to their eventually being supplanted by the latter.

Francis turbines were augmented by the development of the Pelton wheel (1889) for small flow rates and high heads and by propeller turbines, first built by Kaplan in 1913, for large flows at low heads. Kaplan's variable-pitch propeller turbine, which still bears his name, was manufactured after 1920. These units, together with the Deriaz mixed-flow turbine (invented in 1956), constitute the arsenal of modern water turbines.

By the mid-19th century, water turbines were widely used to drive sawmills and textile mill equipment, often through a complex system of gears, shafts, and pulleys. After the widespread adoption of the steam engine they did not, however, become a major factor in power generation until the advent of the electric generator made hydroelectric power possible.

The first hydroelectric central station

The world's first hydroelectric central station was built in 1882 in Appleton, Wis., only three years after Thomas Edison's invention of the light bulb. Its output of 12.5 kilowatts was used to light two paper mills and a house. Thereafter hydroelectric power development spread rapidly, though even by 1910 most units delivered only a few hundred to a few thousand kilowatts. Installations with more than 100,000-kilowatt capacity were not built until the 1930s. One of the first large U.S. plants was installed at Hoover Dam on the Colorado River between Nevada and Arizona. It began operating in 1936 and eventually included 17 Francis turbines capable of delivering from 40,000 to 130,000 kilowatts of power, along with two 3,000-kilowatt Pelton wheels.

The first pumped storage plant with a capacity of 1,500 kilowatts was built near Schaffhausen, Switz., in 1909. It made use of a separate pump and turbine, resulting in a relatively large and only barely economical system. The first U.S. plant, built on the Rocky River in Connecticut in 1929, was also only marginally economical. In the United States major work on pumped-storage hydropower began in the mid-1950s, following the success of a plant at Flatiron, Colo. Built in 1954, this facility was equipped with a reversible-pump turbine having a capacity of 9,000 kilowatts.

In highly industrialized countries, such as the United States and the nations of western Europe, most potential sites for hydropower have already been tapped. Environmental concerns relating to the impact of large dams on the upstream watercourse and to the possible effect on aquatic life add to the likelihood that only a few large hydraulic plants will be built in the future.

From about the 1940s to the early 1970s, many small U.S. hydroelectric facilities (primarily those of less than 1,000-kilowatt capacity) were, in fact, closed down because high maintenance and supervision costs made them uneconomical compared to power plants that burn fossil fuels. Even though the increase in fossil-fuel costs since 1973 has led to the rehabilitation of some of these abandoned plants, only a marked increase in fuel prices, coupled with specific needs for irrigation or flood control, is likely to lead to significant new hydroelectric plant construction.

It is estimated that about 75 percent of the potential waterpower in the contiguous United States has already been developed, with the drainage area of the Columbia River in the Pacific Northwest leading in both developed and potential additional power. As of the late 1980s, hydroelectric power met about 13 percent of the total demand for electrical energy in the United States, though this amounts to only 3 percent of the combined U.S. energy usage for mechanical power, heat, light, and refrigeration.

The above considerations do not necessarily apply to such remote areas as Alaska, northern Canada, and Siberia in Russia, or to developing nations in regions of the Himalayas, Africa, and South America. In these areas it is estimated that only 23 percent of the potential waterpower has been developed. For example, less than 1 percent of the estimated 167 million kilowatts available in Alaska has been harnessed to date. Other river basins with large remaining potential capacities include the Fraser River in Canada, the Orinoco in Venezuela, the Brahmaputra in India, and the Yenisey–Angara in Russia. Turbine capacities for some of these remote areas may possibly exceed the current maximum of 740,000 kilowatts per unit.

STEAM TURBINES

A steam turbine consists of a rotor resting on bearings and enclosed in a cylindrical casing. The rotor is turned by steam impinging against attached vanes or blades on which it exerts a force in the tangential direction. Thus a steam turbine could be viewed as a complex series of windmill-like arrangements, all assembled on the same shaft.

Predominance in power generation and propulsion of high-speed vessels

Because of its ability to develop tremendous power within a comparatively small space, the steam turbine has superseded all other prime movers, except hydraulic turbines, for generating large amounts of electricity and for providing propulsive power for large, high-speed ships. Today, units capable of generating more than 1.3 million kilowatts of power can be mounted on a single shaft.

Classifications. Large steam turbines are complex machines that can be classified in various ways. One approach centres on whether rotation is achieved by impulse forces or by reaction forces (see below). This distinction may become somewhat blurred, since many modern machines employ a combination of both methods.

Condensing and noncondensing turbines. Steam turbines are often divided into two types: condensing and noncondensing. In devices of the first type, steam is condensed at below atmospheric pressure so as to gain the maximum amount of energy from it. In noncondensing turbines, steam leaves the turbine at above atmospheric pressure and is then used for heating or for other required processes before being returned as water to the boiler. Compared to the fuel needed for simply converting water into steam (saturated steam), relatively little additional fuel has to be expended to increase the steam generator exit pressure and, especially, the temperature in order to produce superheated steam, which then is employed to drive a turbine. Noncondensing turbines are therefore an economical means of generating power (cogeneration) when substantial amounts of heating or process steam are already needed.

In condensing turbines, substantial quantities of cooling water are required to carry away the heat released during condensation. While noncondensing turbines exhaust steam at or above atmospheric pressure, condensing turbines can condense at pressures of 90 to 100 kilopascals (13 to 14.5 pounds per square inch) below atmospheric pressure. This allows for a much larger expansion of the steam and a larger change in enthalpy (see above), resulting in higher work output and greater efficiency. All central station plants, where efficiency is a prime consideration, employ condensing turbines.

Steam extraction. Steam turbines differ according to whether or not a portion of the steam is extracted from intermediate portions of the turbine. Extraction may be carried out to partially reheat the water fed back to the boiler and thereby significantly increase the efficiency of the power plant. In light of this, turbines may be classified as (1) straight-through turbines, in which there is no extraction (or bleeding), (2) bleeder or extraction turbines, and (3) controlled- (or automatic-) extraction turbines.

Increasing power plant efficiency

In bleeder turbines no effort is made to control the pres-

sure of the extracted steam, which varies in almost direct proportion to the load carried by the turbine. Extraction also reduces the steam flow to the condenser, allowing the turbine exhaust area to be reduced. Controlled-extraction turbines are designed for withdrawing variable amounts of constant-pressure steam irrespective of the load on the turbine. They are frequently selected for industrial use when steam at fixed intermediate pressures is demanded by process operations. Since both extraction pressures and turbine speed should be kept constant, a complex system is required for controlling steam flow, which increases the cost. Controlled-extraction turbines may be designed for both condensing and noncondensing operations.

Reheat and nonreheat turbines. If high-pressure, high-temperature steam is partially expanded through a turbine, the efficiency can be increased by returning the steam to the steam generator and reheating it to approximately its original temperature before feeding it back to the turbine. Single reheat turbines are common in the electric utility industry. For very large units, double reheating may be employed. Nonreheat turbines are currently limited mostly to industrial plants and small utilities.

Multiflow and compound arrangements. Steam entering a turbine at a high pressure and temperature—say, 24,100 kilopascals gauge, or 3,500 pounds per square inch gauge (where gauge denotes pressure above atmospheric value), and 600° C—can have a volume increase of more than a thousandfold if it is expanded to below atmospheric condenser pressures. To keep the steam velocity through the turbine essentially constant, the annular flow area would have to increase more than a thousandfold, necessitating very large diameter casings and excessively long turbine blades near the exit. In large turbines this problem is alleviated by splitting the low-pressure stream into a number of parallel flow sections, as illustrated in Figures 8 and 9 for four-flow units.

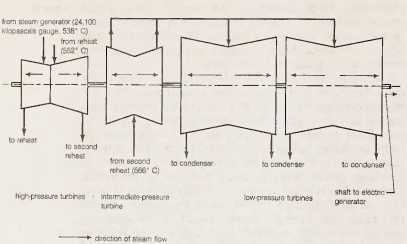

Figure 8: *Schematic of a 3,600-rpm, tandem-compound, four-flow, double-reheat steam turbine.* This unit can produce 725,000 kilowatts with inlet steam at 24,100 kilopascals gauge at 538° C and double reheats to 552° C and 566° C, respectively. The exit blades (or buckets) are 85 centimetres long. The heat rate (see text) at 100 percent of rated output is 7,490 British thermal units per kilowatt-hour (Btu/kWh), 7,950 Btu/kWh at 50 percent output, and 9,330 Btu/kWh at 25 percent output. The first reheat occurs at about 7,140 kilopascals gauge and the second at approximately 2,340 kilopascals gauge when operating at full power.

Tandem-compound and cross-compound turbines

This flow splitting also leads to another method of classification that differentiates between having the whole machine assembled along a single shaft with one generator (tandem-compound turbines), as illustrated in the figures, or utilizing two shafts, each with its own generator (cross-compound turbines).

Principal components. The main parts of a steam turbine are (1) the rotor that carries the blading to convert the thermal energy of the steam into the rotary motion of the shaft, (2) the casing, inside of which the rotor turns, that serves as a pressure vessel for containing the steam (it also accommodates fixed nozzle passages or stator vanes through which the steam is accelerated before being directed against and through the rotor blading), (3) the speed-regulating mechanism, and (4) the support system, which includes the lubrication system for the bearings that support the rotor and also absorb any end thrust developed.

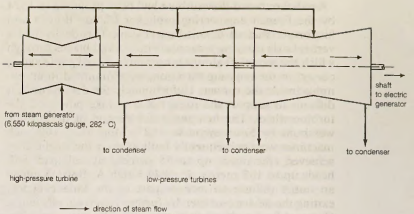

Figure 9: *Schematic of a 1,800-rpm, tandem-compound, four-flow, nonreheat steam turbine for nuclear applications.* The unit is rated at 847,000 kilowatts with steam entering at 6,550 kilopascals gauge and a temperature of about 282° C, which is typical for nuclear power plants. The exit buckets are 96.5 centimetres long. The heat rate is 9,810 Btu/kWh at full output and about 10,400 Btu/kWh at 40 percent output. Similarly, six-flow units operating with steam at 7,580 kilopascals gauge and about 293° C can produce 1,325,000 kilowatts. In this case the exit blades measure 109 centimetres long.

Design considerations. *Blading design.* The turbine blading must be carefully designed with the correct aerodynamic shape to properly turn the flowing steam and generate rotational energy efficiently. The blades also have to be strong enough to withstand high centrifugal stresses and must be sized to avoid dangerous vibrations. Various types of blading arrangements have been proposed, but all are designed to take advantage of the principle that when a given mass of steam suddenly changes its velocity, a force is then exerted by the mass in direct proportion to the rate of change of velocity.

Impulse and reaction blading

Two types of blading have been developed to a high degree of perfection: impulse blading and reaction blading. The principle of impulse blading is illustrated in the schematic diagram of Figure 10 for a first stage. A series of stationary nozzles allows the steam to expand to a lower pressure while its velocity and kinetic energy increase. The steam is then directed to the moving passages or buckets where the kinetic energy is extracted. Since there is ideally no pressure drop and no acceleration in the blade passage, the magnitude of the velocity vector in the blades should remain constant. This also implies that the cross-sectional area normal to the flow remains constant, giving rise to the typical shape of a symmetrical impulse blade—namely, thick at the middle and sharp at the ends.

Figure 10 also includes the velocity diagrams for such a stage. Velocities are vectors that are added by the parallelogram law (see ANALYSIS: *Vector and tensor analysis*). The relative velocity of the fluid with reference to the blade at inlet (or exit) added vectorially to the (tangential) velocity of the blade must give the absolute velocity as seen by the stationary passages. That the kinetic energy at the nozzle exit (proportional to the square of the nozzle-leaving velocity) is much larger than that at the blade exit is apparent from the figure. In an ideal impulse stage, this change of kinetic energy is fully converted into useful work. For minimum exit kinetic energy in a symmetrical impulse blade, the rotor velocity should be about one-half of the entering steam velocity.

In an idealized reaction stage, about one-half of the enthalpy drop per stage is effected in the stator passage and the other half in the rotor passage. This implies that the pressure drop is also almost equal in both the stationary and the rotary passages, which tend to look like mirror images of each other. If the flow velocity is subsonic (below the velocity of sound in the fluid), an expanding passage flow will increase its velocity as the pressure drops while the cross-sectional area decreases simultaneously, thus leading to the curved nozzle shape shown in Figure 11.

Since there is no pressure drop in an idealized impulse stage, pressure forces on the rotor play no role in this type of

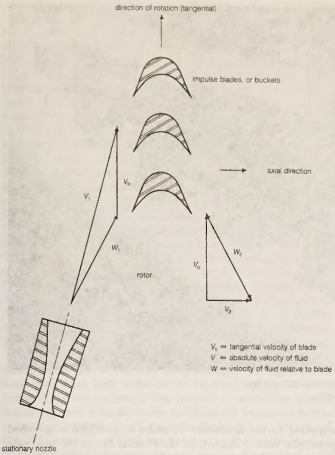

Figure 10: *Schematic of an impulse stage with velocity diagrams.*
The first stage, including a convergent-divergent inlet nozzle, is shown. Ideally there is no change in the magnitude of the relative velocities W between inlet and exit (which are designated by subscripts 1 and 2, respectively). The large inlet absolute velocity V_1 has been reduced to a small absolute exit velocity V_2, which ideally is in the axial direction.

arrangement. By contrast, in a reaction stage, the effect of the changing pressure exerts a net force in the tangential direction (thus turning the wheel) and also in the axial direction. The latter tends to push the rotor into the ends of the casing, requiring a thrust bearing to absorb the axial load. In large turbines the axial load can be reduced by admitting the steam flow in the middle and expanding in both axial directions, as shown in Figures 8 and 9.

There is no need to match the increase of fluid velocity in the stator to that in the rotor (50 percent reaction). Other

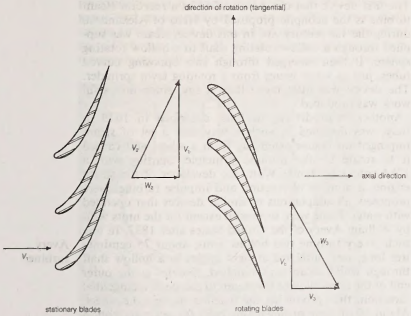

Figure 11: *An idealized 50-percent reaction stage for a steam turbine with velocity diagrams.*
Here, V is absolute velocity of fluid, V_b is blade velocity, and W is velocity of fluid relative to blade. Subscript 1 signifies entering stationary blade (stator), subscript 2 indicates leaving stator or entering rotor, and subscript 3 signifies leaving rotor.

widely used combinations that fall between pure impulse and 50 percent reaction staging have been developed.

The large length of low-pressure blades imposes special requirements on stiffness in addition to aerodynamic shaping. The tangential velocity of the blade near the hub is much smaller than at the blade tip, while the axial through-flow velocity is maintained nearly constant. To match the flow, the blades must be twisted to have the correct approach angle for the incoming steam (see Figure 12) and at the same time avoid possible resonant vibrations.

Turbine staging. Only a small fraction of the overall pressure drop available in a turbine can be extracted in a single stage consisting of a set of stationary nozzles or vanes and moving blades or buckets. In contrast to water turbines where the total head is extracted in a single runner (see above), the steam velocities obtained from the enthalpy drop between steam generator and condenser would be prohibitively high. In addition, the volume increase of the expanding steam requires a large increase in the annular flow area to keep the axial through-flow velocity nearly constant. To this must be added limitations on blade length and blade-tip velocities to avoid excessive centrifugal stresses. In practice, the steam expansion is therefore broken up into many small segments or stages, each with a range of velocities and an appropriate blade size to permit efficient conversion of the thermal energy in the steam to mechanical energy. In modern turbines, three types of staging are employed, either separately or in combination: (1) pressure (or impulse) staging, (2) reaction staging, and (3) velocity-compound staging.

By courtesy of GE Power Generation Operations, General Electric Co.

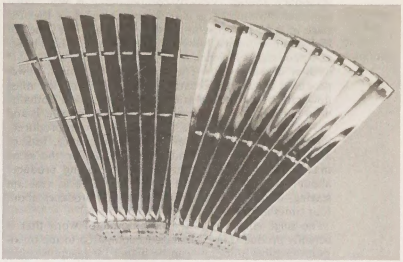

Figure 12: Large low-pressure steam turbine blades.

Pressure staging

Pressure staging uses a number of sequential impulse stages similar to those illustrated in Figure 10, except that the stationary passages also become highly curved nozzles. Pressure-staged turbines can range in power capacity from a few to more than 1.3 million kilowatts. Some manufacturers prefer to build units with impulse stages simply to reduce thrust-bearing loads. An example of a large turbine using impulse staging is shown in Figure 13. Such units may have as many as 20 sequential stages.

Reaction staging

Reaction staging is similar to pressure staging, except that a greater number of reaction stages are required. The first turbine stage, however, is often an impulse stage for controlling the steam flow and for rapidly reducing the pressure in stationary nozzles from its high steam generator value, thereby lowering the pressure that the casing has to withstand. Reaction turbines require about twice as many stages as impulse-staged turbines for the same change in steam enthalpy. The cost and size of the turbines, however, are about the same because blading for pressure staging must withstand greater forces and must therefore be more rigidly constructed. Reaction turbines also have large axial thrust and require heavy-duty thrust bearings.

Velocity-compound staging

In velocity-compound staging a set of stationary nozzles is followed by two sets of moving blades with a stationary row of impulse blades between them to redirect the flow. Ideally this allows twice as much power to be extracted than from a single impulse stage for a given blade-tip

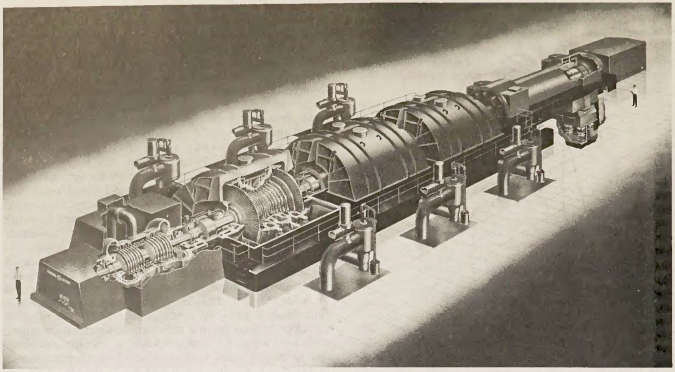

Figure 13: Rendering of an installed 1,800-revolution-per-minute tandem-compound, six-flow, nuclear steam turbine-generator unit rated at more than one million kilowatts.
By courtesy of General Electric Company, Schenectady, N.Y.

velocity. It also permits a large pressure drop through the stationary nozzles. Velocity-compounding is well suited for small turbines; it is also sometimes used as the first stage in large turbines for control purposes. The inherent high steam velocities, however, tend to result in high losses and poor stage efficiencies.

Power development. The theoretical maximum power produced by a turbine can be computed from the mass flow rate of the steam multiplied by the ideal enthalpy drop per unit mass between the steam generator exit and the condenser conditions. The actual power produced, however, is less because of friction, turbulence, leakage around the blade tips, and other losses. For the same maximum blade-tip velocity, pressure staging produces about twice as much ideal power per stage as reaction staging, while velocity-compound staging produces about four times as much.

The stage efficiency—*i.e.*, the amount of work that is actually produced in each stage as compared to the maximum possible amount—can be higher for reaction stages than for impulse stages due to generally lower flow velocities and associated losses. The greater number of stages required, however, results in an overall turbine efficiency that is about the same for both. Efficient stages also require carefully designed seals along the rotor shaft and opposite the rotating blade tips to avoid leakage past the blades.

Control. A turbine driving an electric generator must run at constant speed. In the United States where 60-cycle-per-second alternating current is used, this usually means 3,600 or 1,800 revolutions per minute. (In countries that use 50-cycle current, 3,000 or 1,500 revolutions per minute are the norm.) When the electric power demand on the generator, or the load, changes, the turbine must respond immediately to keep the speed constant. The inlet enthalpy is determined by the exit conditions of the steam generator and the exit enthalpy by the condenser pressure. Neither of these can be varied rapidly. With a fixed enthalpy drop per unit mass, the power output thus can only be controlled by varying the mass flow rate. This is achieved by opening or closing valves leading to the turbine inlet stage. Under partial load, the reduced steam flow results in lower axial velocities along the turbine and thereby alters the velocity diagrams somewhat. Since efficient operation requires a careful match between all velocity directions and blade inlet shapes, part-load operation decreases the efficiency of the turbine.

Overall performance characteristics. The performance of a steam turbine is conventionally measured in terms of its heat rate—*i.e.*, the amount of heat that has to be supplied to the feedwater in order to produce a specified generator power output. In the United States the heat rate is given by the heat input in Btus per hour for each kilowatt-hour of electricity produced by the turbogenerator assembly. The heat rate depends on the steam generator exit temperature and pressure, the condenser pressure, the efficiency of the turbine in converting the thermal energy of the steam into work, the mechanical and bearing losses, the exhaust loss due to the kinetic energy of the steam leaving the final turbine stage, and the generator losses. The lower the heat rate, the less the thermal energy required and the better the efficiency. At constant condenser pressure, the heat rate can be decreased by about 11 percent when going from steam generator exit conditions of 10,000 kilopascals gauge and 538° C to 24,100 kilopascals gauge and 538° C, with a subsequent reheat temperature of 538° C. The higher pressure, however, necessitates costlier equipment to contain the steam and to maintain the same reliability. Part-load operation, with its attendant loss of efficiency, always leads to higher heat rates.

Heat rate

History of steam turbine technology. *Early precursors.* The first device that can be classified as a reaction steam turbine is the aeolipile proposed by Hero of Alexandria, during the 1st century AD. In this device, steam was supplied through a hollow rotating shaft to a hollow rotating sphere. It then emerged through two opposing curved tubes, just as water issues from a rotating lawn sprinkler. The device was little more than a toy, since no useful work was produced.

Another steam-driven machine, described in 1629 in Italy, was designed in such a way that a jet of steam impinged on blades extending from a wheel and caused it to rotate by the impulse principle. Starting with a 1784 patent by James Watt, the developer of the steam engine, a number of reaction and impulse turbines were proposed, all adaptations of similar devices that operated with water. None were successful except for the units built by William Avery of the United States after 1837. In one such Avery turbine two hollow arms, about 75 centimetres long, were attached at right angles to a hollow shaft through which steam was supplied. Nozzles at the outer end of the arms allowed the steam to escape in a tangential direction, thus producing the reaction to turn the wheel. About 50 of these turbines were built for sawmills, cotton gins, and woodworking shops, and at least one was tried on a locomotive. While the efficiencies matched those of contemporary steam engines, high noise levels, difficult speed regulation, and frequent need for repairs led to their abandonment.

Avery turbine

Development of modern steam turbines. No further developments occurred until the end of the 19th century when various inventors laid the groundwork for the modern steam turbine. In 1884 Sir Charles Algernon Parsons, a British engineer, recognized the advantage of employing a large number of stages in series, allowing extraction of the thermal energy in the steam in small steps. Parsons also developed the reaction-stage principle according to which a nearly equal pressure drop and energy release takes place in both the stationary and moving blade passages. In addition, he subsequently built the first practical large marine steam turbines. During the 1880s Carl G.P. de Laval of Sweden constructed small reaction turbines that turned at about 40,000 revolutions per minute to drive cream separators. Their high speed, however, made them unsuitable for other commercial applications. De Laval then turned his attention to single-stage impulse turbines that used convergent-divergent nozzles, such as the one in Figure 14. From 1889 to 1897 de Laval built many turbines with capacities from about 15 to several hundred horsepower. His 15-horsepower turbines were the first employed for marine propulsion (1892). C.E.A. Rateau of France first developed multistage impulse turbines during the 1890s. At about the same time, Charles G. Curtis of the United States developed the velocity-compounded impulse stage.

By 1900 the largest steam turbine-generator unit produced 1,200 kilowatts, and 10 years later the capacity of such machines had increased to more than 30,000 kilowatts. This far exceeded the output of even the largest steam engines, making steam turbines the principal prime movers in central power stations after the first decade of the 20th century. Following the successful installation of a series of 68,000-horsepower turbines in the transatlantic passenger liners *Lusitania* and *Mauretania,* launched in 1906, steam turbines also gained preeminence in large-scale marine applications, first with vessels burning fossil fuels and then with those using nuclear power. Steam generator pressures increased from about 1,000 kilopascals gauge in 1895 to 1,380 kilopascals gauge by 1919 and then to 9,300 kilopascals gauge by 1940. Steam temperatures climbed from about 180° C (saturated steam) to 315° C (superheated steam) and eventually to 510° C over the same time period, while heat rates decreased from about 38,000 to below 10,000 Btus per kilowatt-hour.

The steam turbine as the principal prime mover in large power stations

Recent developments and trends. By 1940, single turbine units with a power capacity of 100,000 kilowatts were common. Ever-larger turbines (with higher efficiencies) have been constructed during the last half of the century, largely because of the steadily rising cost of fossil fuels. This required a substantial increase in steam generator pressures and temperatures. Some units operating with supercritical steam at pressures as high as 34,500 kilopascals gauge and at temperatures of up to 650° C were built before 1970. Reheat turbines that operate at lower pressures (between 17,100 to 24,100 kilopascals gauge) and temperatures (540–565° C) are now commonly installed to assure high reliability. Steam turbines in nuclear power plants, which are still being constructed in a number of countries outside of the United States, typically operate at about 7,580 kilopascals gauge and at temperatures of up to 295° C to accommodate the limitations of reactors. Turbines that exceed one-million-kilowatt output require exceptionally large, highly alloyed steel blades at the low pressure end.

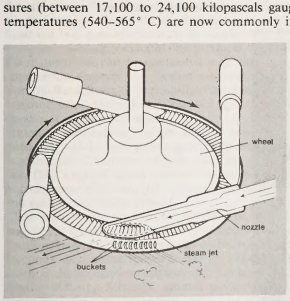

Figure 14: De Laval turbine, showing how the steam is formed into a jet by a specially shaped nozzle and is then deflected by the buckets or vanes on the wheel, causing the wheel to rotate.

Slightly more efficient units with a power capacity of more than 1.3 million kilowatts may eventually be built, but no major improvements are expected within the next few decades, primarily because of the temperature limitations of the materials employed in steam generators, piping, and high-pressure turbine components and because of the need for very high reliability.

Although the use of large steam turbines is tied to electric power production and marine propulsion, smaller units may be used for cogeneration when steam is required for other purposes, such as for chemical processing, powering other machines (*e.g.,* compressors of large central air-conditioning systems serving many buildings), or driving large pumps and fans in power stations or refineries. However, the need for a complete steam plant, including steam generators, pumps, and accessories, does not make the steam turbine an attractive power device for small installations.

(R.A.B./Fr.L.)

WIND TURBINES

Modern wind turbines extract energy from the wind, mostly for electricity generation, by rotation of a propeller-like set of blades that drive a generator through appropriate shafts and gears. The older term windmill is often still used to describe this type of device, although electric power generation rather than milling has become the primary application. As was noted earlier, windmills, together with waterwheels, were widely used from the Middle Ages to the 19th century during the course of which they were supplanted by steam engines and steam turbines. Though they continued to be used for pumping water in rural areas, wind turbines practically disappeared in the 20th century as the internal-combustion engine and electricity provided more reliable and usually less expensive power. Interest in wind turbines for electricity generation was rekindled by the oil crisis of the mid-1970s. High initial costs, intermittent operation, and maintenance costs, however, have prevented wind turbines from becoming a significant factor in commercial power production.

Modern version of the windmill

Types of wind turbines. *Horizontal axis machines.* The best-known machines of this type are the so-called American farm windmills that came into wide use during the 1890s. Such devices consist of a rotor, which may have up to 20 essentially flat sheet-metal blades and a tail vane that keeps the rotor facing into the wind by swiveling the entire rotor assembly. Governing is automatic and overspeeding is avoided by turning the wheel off the wind direction, thus reducing the effective sail area while keeping the speed constant. A typical pump can deliver about 38 litres (10 gallons) per minute to a height of 30 metres at a wind velocity of 6.7 metres per second (15 miles per hour).

Modern wind turbines have from one to four metal blades that operate at much higher rotor-tip speeds than windmills. Each blade is twisted like an airplane propeller. An automatic governor rotates the blades about their support axis to maintain constant generator speed. The Jacobs three-bladed windmill, used widely between 1930 and 1960, could deliver about one kilowatt of power at a wind speed of 6.25 metres per second, a typical average wind velocity in the United States about 18 metres above ground.

High rotor-tip speeds

More recently, large horizontal-shaft, two-bladed turbines have been developed in the United States. The first such device, a unit equipped with a rotor measuring 11.6 metres in diameter, was installed near Sandusky, Ohio, in 1976; its power output was rated at 100 kilowatts. The most recent type of machine, first installed on the island of Oahu in Hawaii, has a rotor diameter of 122 metres with its axis about 76 metres above ground. Its output rating is 6,200 kilowatts at a wind speed of 13 metres per second.

Vertical-axis machines. Devices of this kind, which had

not been used since the early Middle Ages, found a new application after the Finnish engineer S.J. Savonius invented a new type of rotor in 1922. Known as the Savonius rotor, it consists of semicircular blades that can be constructed from little more than the two sections of an oil drum, cut in half along its vertical axis and welded together with an offset from the axis to form an open S (see Figure 15). An advanced version of this machine installed at Manhattan, Kan., during the 1970s generated five kilowatts of electric power in a 12-metre-per-second wind.

Savonius rotor

By courtesy of Gary Johnson, Ph.D.

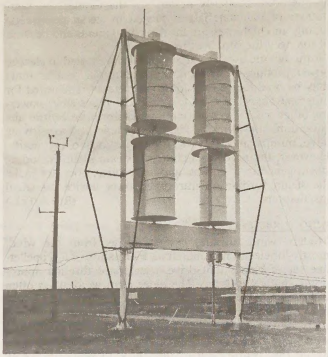

Figure 15: A Savonius rotor.

The most recent vertical wind turbine is based on a machine patented in 1931 by the French engineer G.J.M. Darrieus. Its two blades consist of twisted metal strips tied to the shaft at the top and bottom and bowed out in the middle similar to the blades on a food mixer. A Darrieus turbine with aluminum blades erected in 1980 by the Sandia National Laboratories in New Mexico produced 60 kilowatts in a wind blowing 12.5 metres per second. Turbines of this variety are not self-starting and require an external motor for start-up. Several models of Darrieus turbines have been built since the construction of the Sandia unit (see Figure 16).

Wind farms. A wind farm is a cluster of wind turbines (up to several hundred) erected in areas where there is a nearly steady prevalent wind; such areas generally occur near mountain passes. Wind farms comprising propeller-type units have been set up in Hawaii, California, and New Hampshire (see Figure 17). Capacities range from 10 to 500 kilowatts per unit. During 1984 the total output of all U.S. wind farms exceeded 150 million kilowatt-hours; the entire output was fed into the electric utility network. Though seemingly substantial, this amounted to less than $^{1}/_{100,000}$ of the total electric power generated in the United States.

Limitations on wind power. Not all the kinetic energy of the wind can be extracted, because there must be a finite velocity as the air leaves the blading. It can be shown that the maximum efficiency (energy extracted divided by energy available in the captured wind area) obtainable is about 59 percent, although actual wind turbines extract only a portion of this amount. Currently, the maximum efficiency obtainable with a propeller-type windmill is roughly 47 percent; this occurs when the propeller-tip speed is between five and six times the wind velocity. For a given rotor speed, it drops rapidly as the wind velocity decreases. The power obtainable varies as the square of the rotor diameter and the cube of the wind velocity. Thus the theoretical maximum energy obtainable from a rotor with a diameter of 30 metres in a wind with a speed of 14 metres per second would be about 690 kilowatts. If the wind speed decreases to 7 metres per second, the theoretical maximum drops to about 86 kilowatts. At this lower wind speed, it would require more than 17,000 wind turbines (with rotors of 30 metres across) operating at an efficiency of 40 percent to match the output of a single large one-million-kilowatt central power station. When these limitations are coupled to the need for suitable sites with steady winds, it becomes apparent that wind turbines alone will not play a major role in meeting the power demands of an industrialized nation.

Amount of kinetic energy extracted from the wind

Development of wind turbines. The origin and development of the traditional windmill and other predecessors of modern wind turbines were described above in *History of energy-conversion technology.* The emergence and evolution of wind-driven devices for electric power generation are briefly surveyed here.

The development of the electric generator aroused some interest in the wind as a "free" power source. The first windmill to drive a generator was built in 1890 by P. LaCour in Denmark, using patent sails and twin fantails on a steel tower.

Adopting the ideas gained from airfoil and aircraft propeller designs, windmill designers and manufacturers began to replace broad windmill sails with a few slender propeller-like blades. In 1931 the first propeller wind turbine was erected in the Crimea. From the 1940s, experimental twin-blade turbines were constructed in the United States and later in Scotland and France. In The Netherlands a few old-fashioned mills were adapted to generate electricity. Today, wind turbines for electric power generation are most commonly propeller-type machines. (Fr.L.)

By courtesy of the U.S. Department of Energy

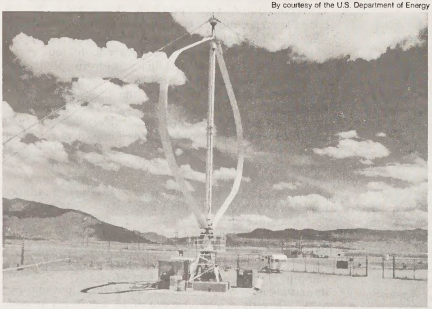

Figure 16: A Darrieus wind turbine.



Figure 17: A wind farm consisting of hundreds of propeller-type wind turbines.

Internal-combustion engines

An internal-combustion (IC) engine is any of a group of devices in which the reactants of combustion (oxidizer and fuel) and the products of combustion serve as the working fluids of the engine. Such an engine gains its energy from heat released during the combustion of the nonreacted working fluids, the oxidizer–fuel mixture. This process occurs within the engine and is part of the thermodynamic cycle of the device. Useful work generated by an IC engine results from the hot, gaseous products of combustion acting on moving surfaces of the engine, such as the face of a piston, a turbine blade, or a nozzle.

Major classes of IC engines

Internal-combustion engines are divided into two groups: continuous-combustion engines and intermittent-combustion engines. The continuous-combustion engine is characterized by a steady flow of fuel and oxidizer into the engine. A stable flame is maintained within the engine (*e.g.*, jet engine). The intermittent-combustion engine is characterized by periodic ignition of air and fuel and is commonly referred to as a reciprocating engine. Discrete volumes of air and fuel are processed in a cyclic manner. Gasoline piston engines and diesel engines are examples of this second group.

Internal-combustion engines can be delineated in terms of a series of thermodynamic events. In the continuous-combustion engine, the thermodynamic events occur simultaneously as the oxidizer and fuel, and the products of combustion flow steadily through the engine. In the intermittent-combustion engine, by contrast, the events occur in succession and are repeated for each full cycle.

With the exception of rockets (both solid-rocket motors and liquid-propellant rocket engines), internal-combustion engines ingest air, then either compress the air and introduce fuel into the air or introduce fuel and compress the air–fuel mixture, burn the air–fuel mixture, extract work from the hot, gaseous products of combustion by expansion, and ultimately exhaust the products of combustion. Their operation can be contrasted with that of external-combustion engines (*e.g.*, steam engines), in which the working fluid does not chemically react and energy gain is achieved solely through heat transfer to the working fluid by way of a heat exchanger.

Examples of IC engines

Internal-combustion engines are the most broadly applied and widely used power-generating devices currently in existence. Examples include gasoline (or spark-ignition [SI]) engines, diesel engines (sometimes referred to as compression-ignition [CI] engines), gas-turbine engines, and rocket propulsion systems.

The most common internal-combustion engine is the four-stroke gasoline-powered, homogeneous-charge, spark-ignition engine. This is because of its outstanding performance as a prime mover in the ground-transportation industry. Spark-ignition engines also are used in the aeronautics industry; however, aircraft gas turbines have become the prime movers in this sector due to the emphasis of the aeronautics industry on range, speed, and passenger comfort. The domain of internal-combustion engines also includes such exotic devices as supersonic combustion ramjet engines (scramjets), as typified by the space plane, and sophisticated rocket engines and motors, as those used on the U.S. Space Shuttle and other space vehicles.

It is the versatility and cost—both capital and operational—of conventional internal-combustion engines that have led to their widespread use in contemporary energy production. (C.L.P.II)

GASOLINE ENGINES

General characteristics. The gasoline engine is an intermittent-combustion engine. It is powered by the combustion of a premixed charge of air and gasoline, which is ignited electrically by a spark.

Most gasoline engines are of the so-called reciprocating piston type, but recent developments suggest that superior performance in some respects may be obtained from either rotary piston or turbine types (see below). Several terms are unique to the reciprocating piston engine. The piston–cylinder arrangement defines all terms relative to the size, location, and position of the piston within the cylinder (see Figure 18). Bore is the inner diameter of the cylinder. The volume at bottom dead centre (VBDC) is defined as the volume occupied between the cylinder head and the piston face when the piston is farthest from the cylinder head. The volume at top dead centre (VTDC) is that volume occupied when the piston is closest to the cylinder head; the distance between the piston face and cylinder head at VTDC is called the clearance. The distance traveled by the piston between its VTDC and VBDC locations is the stroke. The compression ratio of a reciprocating engine is

Basic terms

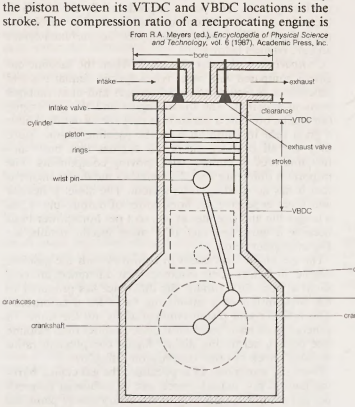

Figure 18: Typical piston–cylinder arrangement of a gasoline engine.

the ratio of VTDC to VBDC normalized to the VTDC value—*i.e.*, (VBDC/VTDC):1.

In all internal-combustion engines the products of combustion act directly on piston or rotor surfaces, whereas the external-combustion engine employs a secondary working fluid that is interposed between the combustion chamber and the power-producing elements. Fundamentally, the steam engine operates with a high-pressure working medium produced by utilizing the expansion accompanying the vaporization of a liquid (see above); by contrast, the internal-combustion engine utilizes the large volume of high-temperature combustion products that, when confined, become a high-pressure gaseous medium.

Combustion processes

Classification. The many types of internal-combustion engines can be grouped in a number of different ways on the basis of similarities among them. Important methods of classification include application, type of fuel and method of injection, ignition, reciprocating piston or rotary, cylinder arrangement, strokes per cycle, cooling system, and valve type and location. These various classifications will be discussed further as the various engine types are described.

Valve type and arrangement. Valves for controlling intake and exhaust may be located overhead, on one side, side and overhead, or on opposite sides of the cylinder. These are all the so-called poppet or mushroom valves consisting of a stem with one end enlarged to form a head that permits flow through a passage surrounding the stem when raised from its seat and prevents flow when the head is moved down to contact the valve seat formed in the cylinder block.

Another group of engines uses sliding valves that are usually of the sleeve type surrounding the cylinder bore.

Pressure application. Some power plants use the same combustion principle but apply the pressure resulting from combustion to different mechanical elements. There are, for example, gas-turbine engines in which the products of combustion are directed through nozzles against the blades of a turbine rotor to cause it to rotate. In the jet engine the products of combustion simply flow through a nozzle, and the reaction force tends to move the nozzle in the opposite direction.

The Wankel and Tri-Dyne engines (see below) burn the fuel within the engine; they are rotary and do not have conventional cylinders fitted with reciprocating pistons. Instead, the gas pressure acts on surfaces formed by the configuration of a rotor. Both gas-turbine and jet engines have combustion furnaces separate from the power-producing units. The power is produced by the action of the products of combustion on the blades of the turbine or the interior wall of the jet nozzle (see *Gas-turbine engines* and *Jet engines* below).

Rotary engines

Comparison with other engines. When the gasoline engine is compared with other types, certain similarities and differences as well as some advantages and disadvantages become apparent. The diesel engine and the gas engine (an engine utilizing a gas such as propane as the fuel) have a good deal in common with the gasoline engine, since they are all cylinder-and-piston engines that burn air–fuel mixtures in contact with moving components. The important difference that distinguishes the diesel engine is that it has no spark-ignition system. The diesel is heavier and more expensive per horsepower of output, but it has a longer life and operates at less cost per horsepower-hour because it burns less fuel. (For more specific details, see *Diesel engines* below.)

The gas engine has much in common with the gasoline engine; in fact, in some instances their differences are very slight at best. Structurally, the difference lies primarily in the substitution of a gas-mixing valve for a carburetor. The cylinder and piston configurations are the same. In general, gases have better antiknock qualities than gasoline (see below), permitting slightly higher compression ratios without knock or other combustion difficulties.

The gas engine

From the standpoint of application, the gas engine burning natural gas, manufactured gas, or industrial by-product gas is limited primarily to stationary power plant use because it must remain connected to the gas pipeline. If, however, the fuel is liquefied petroleum gas, sometimes called bottled gas, the containers of gas can be carried in a vehicle, leading to much flexibility in applications. The present obstacle is that facilities are not readily available for replenishing the gas supply. Dual carburetors have been produced experimentally that make it possible to operate an engine on either liquefied petroleum gas or gasoline; thus dual gas–gasoline engines are a distinct possibility.

Engine types. Of the different techniques for recovering the power from the combustion process the most important so far has been the four-stroke cycle, a conception now more than 100 years old.

Four-stroke cycle. The four-stroke cycle is illustrated in Figure 19. With the inlet valve open, the piston first descends on the intake stroke. An explosive mixture of gasoline vapour and air is drawn into the cylinder by the partial vacuum thus created. The mixture is compressed as the piston ascends on the compression stroke with both valves closed. As the end of the stroke is approached, the charge is ignited by an electric spark. The power stroke follows, with both valves still closed and the gas pressure, due to the expansion of the burned gas, pressing on the piston crown. During the exhaust stroke, the ascending piston forces the spent products of combustion through the open exhaust valve. The cycle then repeats itself. Each cycle thus requires four strokes of the piston—intake, compression, power, and exhaust—and two revolutions of the crankshaft.

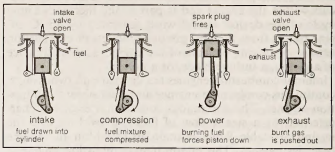

Figure 19: Strokes of the four-stroke cycle.

A disadvantage of the four-stroke cycle is that only half as many power strokes are completed as in the two-stroke cycle (see below) and only half as much power can be expected from an engine of a given size at a given operating speed. The four-stroke cycle, however, provides more positive clearing out of exhaust gases (scavenging) and reloading of the cylinders, reducing the amount of loss of fresh charge to the exhaust.

Two-stroke cycle. In the original two-stroke cycle (as developed in 1878), the compression and power stroke of the four-stroke cycle are carried out without the inlet and exhaust strokes, thus requiring only one revolution of the crankshaft to complete the cycle. Figure 20 illustrates the two-stroke-cycle engine of a so-called uniflow type in which the fresh fuel mixture is forced into the cylinder through circumferential ports by a rotary blower. The exhaust gases pass through poppet valves in the cylinder head that are opened and closed by a cam-follower mechanism. The valves are timed to begin opening toward the end of the power stroke after the cylinder pressure has dropped appreciably. The inlet ports in the cylinder wall start to uncover after the exhaust opening has decreased the cylinder pressure to the inlet pressure produced by the blower. The exhaust valves are allowed to remain open for a few

Uniflow two-stroke-cycle engine

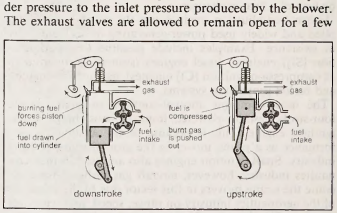

Figure 20: Blower-scavenged, two-stroke-cycle engine with uniflow scavenging.

degrees of crank rotation after the inlet ports have been covered by the rising piston on the compression stroke, thus allowing the persistency of flow more thoroughly to scavenge the cylinder. The compression and power strokes are similar to those of the four-stroke engine.

Crankcase compression

A simplified version of the two-stroke-cycle engine was developed some years later (introduced in 1891) by using crankcase compression to pump the fresh charge into the cylinder. Instead of intake ports extending entirely around the lower cylinder wall, this engine has intake ports only halfway around; a second set of ports starts a little higher in the cylinder wall in the other half of the cylinder bore. These larger ports lead to the exhaust system. The inlet ports connect to a transfer passage leading to the fully enclosed crankcase. A spring-loaded inlet valve admits air into the crankcase on the upward, or compression, stroke of the piston. Air trapped in the crankcase is compressed by the descent of the piston on its power stroke. The piston thus uncovers the exhaust ports near the end of the power stroke and slightly later it uncovers the inlet or transfer port on the opposite side of the cylinder to admit the compressed fresh mixture from the crankcase. The top face of the piston is designed to provide a deflector or baffle that directs the fresh load upward on the inlet side of the cylinder and then downward on the exhaust side, thus pushing the spent gases of the previous cycle out through the exhaust port on that side. This outflow continues after the inlet ports are covered by the rising piston on the compression stroke until the exhaust ports are covered and compression of the fresh load begins. This loading process, called loop scavenging, is the simplest known method of replacing the exhaust products with a fresh mixture and completing the cycle with only compression and power strokes.

Loop scavenging

Such a system is used in many small gasoline engines (*e.g.*, small outboard motors) and for gasoline-powered appliances. A disadvantage is that the return flow of the gases causes a slight loss of fresh charge through the exhaust ports. Because of this loss, carburetor engines operating on the two-stroke cycle lack the fuel economy of four-stroke engines. The loss can be avoided by equipping them with fuel-injection systems (see below) instead of carburetors and injecting the fuel directly into the cylinders after scavenging. Such an arrangement is attractive as a means of attaining high power output from a relatively small engine, and development of the turbocharger (see below *Supercharger*) for this application holds promise of further improvement.

Opposed-piston engine. The opposed-piston engine also provides uniflow scavenging. This engine (Figure 21A) has two pistons moving in opposite directions in the same cylinder. Two sets of ports extending entirely around the cylinder bore are so located that one set is covered and uncovered by one piston and the other set is controlled by the second piston. A second crankshaft, to which the upper pistons are attached, is located at the top of the engine and the two shafts are connected by gears.

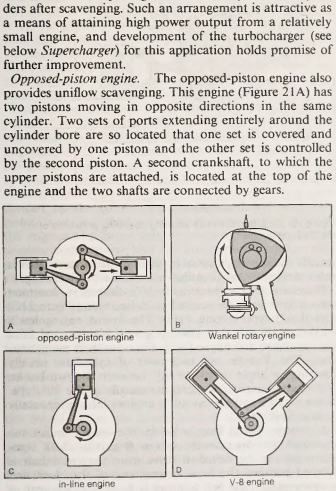

Figure 21: Certain types of gasoline engines.

The opposed-piston design has two major advantages: reciprocating masses move in opposite directions, providing excellent balance; and the poppet valves necessary in other uniflow-scavenged two-stroke-cycle engines are eliminated.

Wankel rotary engine. A rotary-piston internal-combustion engine developed in Germany is radically different in structure from conventional reciprocating piston engines. The engine was conceived by Felix Wankel, a specialist in the design of sealing devices, and experimental units were built and tested by a German firm beginning in 1956. Instead of pistons that move up and down in cylinders, the Wankel engine has an equilateral triangular orbiting rotor (see Figure 21B). The rotor turns in a closed chamber and the three apexes of the rotor maintain a continuous sliding contact with the curved inner surface of the casing. The curve-sided rotor forms three crescent-shaped chambers between its sides and the curved wall of the casing. The volumes of the chambers vary with the rotor motion. Maximum volume is attained in each chamber when the side of the rotor forming it is parallel with the minor diameter of the casing, and the volume is reduced to a minimum when the rotor side is parallel with the major diameter. Shallow pockets recessed in the flank of the rotor control the shape of the combustion chambers and establish the compression ratio of the engine.

Action of the rotor

In turning about its central axis the rotor must follow a circular orbit about the geometric centre of the casing. The necessary orbiting rotation is attained by means of a central bore in the rotor in which an internal gear is fitted to mesh with a stationary pinion fixed immovably to the centre of the casing. The rotor is guided by fitting its central bore to an eccentric formed on the output shaft that passes through the centre of the stationary pinion. This eccentric also harnesses the rotor to the shaft so that torque is applied when gas pressure is exerted against the rotor flanks as the fuel and air charges burn. A 3-to-1 gear ratio causes the output shaft to turn three times as fast as the rotor turns about the eccentric. Each quarter turn of the rotor completes an expansion or a compression, permitting intake, compression, expansion, and exhaust to be accomplished during one turn of the rotor. The only moving parts are the rotor and the output shaft.

The fuel mixture is supplied by a carburetor and enters the combustion chambers through an intake port in one of the end plates of the casing. An exhaust port is formed in one of the flattened sides of the casing wall and a spark plug is located in a pocket communicating with the chambers through a small throat in the opposite side of the casing wall.

The rotor and its gears and bearings are lubricated and cooled by oil circulating through the hollow rotor. The apex vanes are lubricated by a small amount of oil added to the fuel in proportions as low as 1 to 200. Water is circulated through cooling jackets in the casing, the entrance to which is located adjacent to the spark plug where the temperature tends to be highest.

Maintaining pressure-tight joints by suitable seals at the apexes and on the end faces of the rotor is a major design problem. Radial sliding vanes are fitted in slots at the three apex edges and kept in contact with the casing by expander springs. The end faces of the rotor are sealed by arc-shaped segmental rings fitted in grooves close to the curved edges of the rotor and pressed against the casing by flat springs.

Advantages of the Wankel engine

The major advantages of the Wankel engine are its small space requirements and low weight per horsepower, smooth and vibrationless operation, quiet operation, and low manufacturing costs resulting from mechanical simplicity. The absence of inertial forces from reciprocating parts and the elimination of spring-closed poppet valves permit operation at much higher speed than is practical for reciprocating piston engines, an advantage because shaft speed must be high for optimum performance. The induction of fresh fuel mixture and exhaust are more effective because the ports are opened and closed more rapidly than with poppet valves, and gas flow through them is almost continuous. Heat transfer and the resulting cooling requirement are low because the jacketed surface is small. Fuel economy is at least as good as that of conventional

gasoline engines, providing knock-free combustion with a wider range of permissible fuels. Lower weight and a lower centre of gravity make it much safer in an automobile in the event of a collision. There are approximately one third as many parts in a Wankel engine as in a typical six-cylinder automobile engine.

Tri-Dyne rotary engine. The Tri-Dyne engine, a British design, consists of three rotors (Figure 22). The large, triangular central rotor is called the power rotor. The other two are a combustion rotor and a barrier valve. The power rotor turns in the opposite direction from the combustion rotor and barrier valve. It has three curved lobes that fit into three semicircular cavities in the periphery of each of the two smaller rotors. The three are geared together by spur-shaped gears on the end of each rotor; all of them turn at the same speed. The motion is entirely rotary with no eccentricity. The three cavities in the combustion rotor form the combustion chambers and the profiles of all three rotors are such that, while not actually touching each other, they interact to connect these cavities alternately with the inlet and exhaust pipes and isolate them during the combustion process. It is not necessary that the cavities be positively sealed because of the high speed of operation. Clearance of 0.1 millimetre (0.004 inch) is provided between the interacting surfaces. Two spark plugs are installed in the casing at a point where they communicate with the combustion rotor cavities as they pass at the instant of firing. The advantage of the Tri-Dyne engine over the Wankel engine lies in the elimination of the seals that the latter requires at the apexes of its triangular rotor that limit the speed at which it can operate and that are difficult to lubricate.

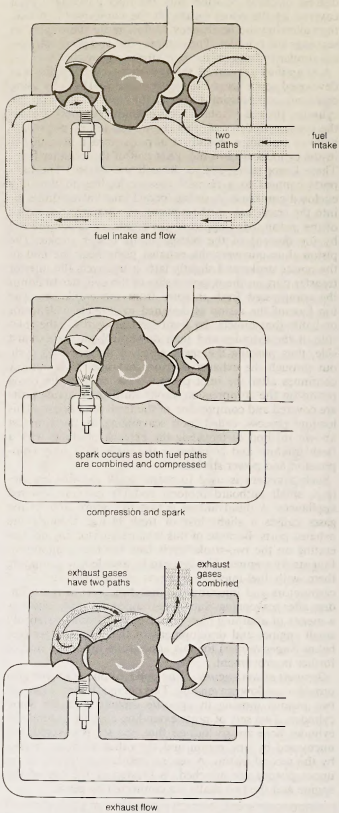

Figure 22: Simplified sketches showing operating principles of the Tri-Dyne engine.

Engine construction and operation. The overall structure of a gasoline engine depends almost entirely upon the intended application. Many components require only slight modification. Apart from the type of cycle (two- or four-stroke) the provision for mounting is the main structural difference among automotive, marine, stationary, and aviation engines. When a clutch and transmission are used, as in automobiles, the engine is commonly of the so-called unit-power-plant type with a bell-shaped housing surrounding the flywheel and attached to the rear flange of the cylinder block integral with, or attached to, the transmission gear case. The clutch is incorporated in the flywheel of the engine. Three-point suspension is used in such engines; that is to say, projections on each side of the bell housing fit into the vehicle side frame members and a central tubular extension at the centre of the front end of the cylinder block attaches to the front cross member of the frame. This construction permits some flexing of the vehicle frame without stressing the basic structure of the engine.

Unit-power-plant type

The following description of general engine construction indicates the essential components of an engine and introduces the nomenclature of the various parts. The four-stroke-cycle automobile engine is used as the basic type. Figure 23 shows a cross section of a typical automobile engine with the principal parts indicated.

Cylinder block. The main structural member of all automotive engines is a cylinder block that usually extends upward from the centre line of the main support for the crankshaft to the junction with the cylinder head. The block serves as the structural framework of the engine and carries the mounting pad by which the engine is supported in the chassis. Large, stationary power-plant engines and marine engines are built up from a foundation or bedplate and have upper and lower crankcases that are separate from the cylinder assemblies. The cylinder block of an automobile engine is a casting with appropriate machined surfaces and threaded holes for attaching the cylinder head, main bearings, oil pan, and other units. The crankcase is formed by the portion of the cylinder block below the cylinder bores and the stamped metal oil pan that forms the lower enclosure of the engine and also serves as a lubricating oil reservoir or sump.

Crankcase

The cylinders are openings of circular cross section that extend through the upper portion of the block with interior walls bored and polished to form smooth, accurate bearing surfaces. The cylinders of heavy-duty engines are usually fitted with removable liners made of metal that is more wear-resistant than that used in the block casting.

There are two arrangements of cylinders in common automotive use—the vertical or in-line type (Figure 21C) and the V type (Figure 21D). The in-line engine has a single row of cylinders extending vertically upward from the crankcase and aligned with the crankshaft main bearings. The V type has two rows of cylinders, usually forming an angle of 60° or 90° between the two banks. V-8 engines (eight cylinders) are usually of the 90° type. Some small 6-cylinder aviation engines have horizontally opposed cylinders.

A passage bored lengthwise in the block houses the camshaft that operates the valves. A gear or chain compartment for the camshaft drive from the crankshaft is formed between the front or rear end of the block and a cover plate. The bell housing is formed at the rear of the cylinder block to enclose the flywheel and provide for

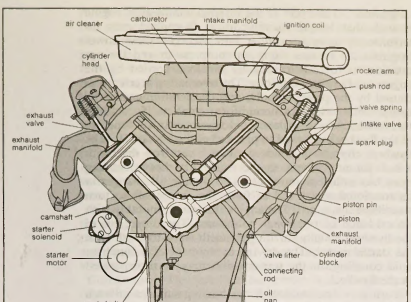

Figure 23: Cross section of a V-8 engine.
By courtesy of Cadillac Motor Car Division

attachment of a transmission housing. Water jackets are formed around the cylinders with suitable cored connecting passages for circulation of the coolant.

Block design

The design of the cylinder block is affected by the location of the valves of the four-stroke-cycle engine and by the provision of cylinder ports in the two-stroke type. An overhead-valve engine, which has largely replaced the L-head type, has its valves entirely in the cylinder head. The cylinder block of the L-head engine is extended to one side of the cylinder bores, with the valve seats and passages for inlet and exhaust, together with the valve guides, formed in this extension of the block. The cylinder head then becomes merely a water-jacketed cover, providing threaded locations for the spark plugs and with its underside so profiled that a combustion chamber of desired size and shape is formed above each cylinder bore. The shape of the space forming the combustion chamber when the piston is at its closest approach to the cylinder head and volume contained therein in relation to the piston displacement volume are extremely important in their effect on performance. The cylinder head of the valve-in-head engine is narrower and deeper and carries the valve seats, valve guides, and valve ports.

Combustion chamber. The size of the combustion chamber relative to the volume displaced by the piston establishes the compression ratio of the engine. The piston displacement is the volume swept by the piston during one stroke and is equal to the cross-sectional area of the cylinder multiplied by the length of the stroke. The larger volume above the piston at the lowest point in its stroke, divided by the combustion-chamber volume when the piston is at its highest point, is the compression ratio of the engine. The larger volume is the sum of the piston-displacement volume and the combustion-chamber volume. The compression ratio may thus be expressed as the ratio of the sum of the piston displacement volume and the combustion-chamber volume to the combustion-chamber volume. Compression ratio is the most important factor affecting the theoretical efficiency of the engine cycle. Because increasing the compression ratio is the best way to improve efficiency, compression ratios on automobile engines have tended to increase. This requires stronger, more durable materials.

Importance of compression ratio

Pistons. The pistons are cup-shaped cylindrical castings of steel or aluminum alloy. The upper, closed end, called the crown, forms the lower surface of the combustion chamber and receives the force applied by the combustion gases. The outer surface is machined to fit the cylinder bore closely and is grooved to receive piston rings that seal the gap between the piston and the cylinder wall. In the upper piston grooves there are plain compression rings that prevent the combustion gases from blowing past the piston. The lower rings are vented to distribute and limit the amount of lubricant on the cylinder wall. Piston pin supports (bosses) are cast in opposite sides of the piston and hardened steel pins fitted into these bosses pass through the upper end of the connecting rod.

Connecting rod and crankshaft. A forged steel connecting rod connects the piston to a throw (offset portion) of the crankshaft and converts the reciprocating motion of the piston to the rotating motion of the crank. The lower, larger end of the rod is bored to take a precision bearing insert lined with Babbitt or other bearing metal and closely fitted to the crankpin. V-type engines usually have opposite cylinders staggered sufficiently to permit the two connecting rods that operate on each crank throw to be side by side. Some larger engines employ fork-and-blade rods with the rods in the same plane and cylinders exactly opposite each other.

V-type engines

Each connecting rod in an in-line engine or each pair of rods in a V-type engine is attached to a throw of the crankshaft. Each throw consists of a crankpin with a bearing surface, on which the connecting rod bearing insert is fitted, and two radial cheeks that connect it to the portions of the crankshaft that turn in the main bearings, supported by the cylinder block. Sufficient throws are provided to serve all the cylinders, and the angles between them equal the angular firing intervals between the cylinders. The throws of a six-cylinder, four-stroke-cycle crankshaft are spaced 120° apart so that the six cylinders fire at equal intervals in two full rotations of the shaft. Those of an eight-cylinder engine are 90° apart. The position of each throw along the shaft depends upon the firing order of the cylinders. Firing sequence is chosen to distribute the power impulses along the length of the engine to minimize vibration. Consideration is also given to the fluid flow pattern in the intake and exhaust manifolds. The standard firing order for a six-cylinder engine is 1-5-3-6-2-4, which illustrates the practice of alternating successive impulses between the front and rear valves of the engine whenever possible. Balance is further improved by adding counterweights to the crankshaft to offset the eccentric masses of metal in the crank throws.

The crankshaft design also establishes the length of the piston stroke because the radial offset of each throw is equal to half the stroke imparted to the piston. The ratio of the piston stroke to the cylinder bore diameter is an important design consideration. In the early years of engine development, no logical basis for the establishment of this ratio existed, and a range from unity to $1^1/_2$ was used by different manufacturers. As engine speeds increased, however, and it became apparent that friction horsepower increased with piston speed rather than with crankshaft rotating speed, there began a trend toward short-stroke engines. Strokes were shortened to as much as 20 percent less than the bores.

Crank-throw layout

From the requirement for the two-cylinder engine a general rule for the layout of the throws of four-stroke-cycle multicylinder crankshafts can be expressed. Regardless of the number of cylinders, two pistons must arrive at top dead centre (see above) in unison so that a second cylinder is ready to fire exactly 360° after each cylinder fires. Half of the cylinders then will fire during each turn of the crankshaft. To follow this rule, there must be an even number of cylinders in order that there may be pairs of cylinders whose pistons move in unison.

An eight-cylinder engine fires each time its crankshaft makes a quarter turn if the intervals between impulses are equal. The crankshaft for an eight-cylinder, in-line engine is designed with each of its eight throws a quarter turn away from another throw.

For best lengthwise balance, the cylinders whose pistons are in phase are the first and last cylinders of an in-line engine, the second and next to the last, continuing in that order with crank throws that are in alignment equidistant from the centre of the engine.

Valves, pushrods, and rocker arms. The valve-in-head engine has pushrods that extend upward from the cam followers to rocker arms mounted on the cylinder head that contact the valve stems and transmit the motion produced by the cam profile to the valves. Clearance (usually

termed tappet clearance) must be maintained between the ends of the valve stems and the lifter mechanism to assure proper closing of the valves when the engine temperature changes. This is done by providing pushrod length adjustment or by the use of hydraulic lifters.

Noisy and erratic valve operation can be eliminated with entirely mechanical valve lifter linkage only if the tappet clearance between the rocker arms and the valve stems is closely maintained at the specified value for the engine as measured with a thickness gauge. Hydraulic valve lifters, now commonly used on automobile engines, eliminate the need for periodic adjustment of clearance.

Hydraulic valve lifters

The hydraulic lifter comprises a cam follower that is moved up and down by contact with the cam profile, and an inner bore into which the valve lifter is closely fitted and retained by a spring clip. The valve lifter, in turn, is a cup closed at the top by a freely moving cylindrical plug that has a socket at the top to fit the lower end of the pushrod. This plug is pushed upward by a light spring that is merely capable of taking up the clearance between the valve stem and the rocker arm. A small hole is drilled in the bottom of the valve-lifter cup to admit lubricating oil that enters the cam follower from the engine lubricating system through a passage in the cylinder block. A small steel ball serves as a check valve to admit the oil into the valve-fitter cup but prevent its escape. When the clearance in the entire linkage between the cam profile and the valve stem is being taken up by the spring in the valve lifter, oil flows into the lifter chamber past the ball check and is trapped there to maintain this no-clearance condition as the engine operates. Expansion or contraction of the valve linkage is compensated by oil seepage from the lifter to correct for expansion of parts and oil flow into the chamber if clearance tends to be produced between the pushrod and the lifter. Complete closure of the valve is then assured at all times without tappet noise.

The intake valve must be open while the piston is descending on the intake stroke of the piston, and the exhaust valve must be open while the piston is rising on the exhaust stroke. It would seem, therefore, that the opening and closing of the two valves would occur at the appropriate top and bottom dead-centre points of the crankshaft. The time required for the valves to open and close, however, and the effects of high speed on the starting and stopping of the flow of the gases requires that for optimum performance the opening events occur before the crankshaft dead-centre positions and that the closing events be delayed until after dead centre.

Valve timing

All four valve events, inlet opening, inlet closing, exhaust opening, and exhaust closing, are accordingly displaced appreciably from the top and bottom dead centres. Opening events are earlier and closing events are later to permit ramps to be incorporated in the cam profiles to allow gradual initial opening and final closing to avoid slamming of the valves. Ramps are provided to start the lift gradually and to slow the valve down before it contacts its seat. Early opening and late closure are also for the purpose of using the inertia or persistence of flow of the gases to assist in filling and emptying the cylinder.

Camshaft. The camshaft, which opens and closes the valves, is driven from the crankshaft by a chain drive or gears on the front end of the engine. Because one turn of the camshaft completes the valve operation for an entire cycle of the engine and the four-stroke-cycle engine makes two crankshaft revolutions to complete one cycle, the camshaft turns half as fast as the crankshaft. It is located above and to one side of the crankshaft, which places it directly under the valves of the L-head engine or the pushrods that extend down from the rocker arms of the valve-in-head engine. Because of the long pushrods and the rocker arms, the speed of the valve-in-head engine is limited to that at which the cam followers can remain in contact with the cams when the valves are closing. Above that limiting speed the valves are said to float and their motion tends to become erratic. For this reason, the overhead-camshaft engine is increasing in popularity. Located immediately above the valves, this type of camshaft is driven either by a vertical shaft and bevel gears or by a cog belt.

Overhead camshafts

Flywheel. The cycle of the internal-combustion engine is such that torque (turning force) is applied only intermittently as each cylinder fires. Between these power impulses the pistons rising on compression and the opposition to rotation caused by the load carried by the engine apply negative torque. The alternating acceleration caused by the power impulse and deceleration caused by compression results in nonuniform rotation. To counter this tendency to slow down and speed up is the function of the flywheel, attached to one end of the crankshaft. The flywheel consists of a heavy circular cast-iron disk with a hub for attachment to the engine. Its heavy rotating mass has sufficient momentum to oppose all changes in its rotational speed and to force the crankshaft to turn steadily at this speed. The engine thus runs smoothly with no evidence of rotational pulsations. The outer rim of the flywheel usually carries gear teeth so as to mesh with the starter motor. The driving component of a clutch or fluid coupling for the transmission may be incorporated in the flywheel.

Bearings. The crankshaft has bearing surfaces on each crank throw and three or more main bearings. These are heavily loaded because of the reciprocating forces at each cylinder applied to the crankshaft and the weight of the crankshaft and flywheel. All but the smallest engines use split shell bearings, usually made of bronze with Babbitt-metal linings. The surface material is sufficiently soft to minimize the possibility of scoring the crankshaft in the event of inadequate lubrication. The smallest engines usually have cast Babbitt bearings. A small amount of bearing clearance is necessary to permit an oil film to separate the surfaces.

Ignition. Electric ignition systems may be classified as magneto and battery-and-coil systems. Although these are similar in basic principle, the magneto is self-contained and requires only the spark plugs and connecting wires to complete the system, whereas the battery-and-coil system involves several separate components. The circuit consists of a battery, one terminal of which is grounded while the other leads through a switch to the primary winding of the coil, and then to a circuit breaker where it is again grounded. Rotation of the circuit-breaker cam opens and closes the primary circuit. The secondary circuit, consisting of several thousand turns of fine wire, leads to the rotor of the distributor, which acts as a rotary switch, selecting the spark plug to be placed in the circuit. Each plug is connected to one of the outer terminals of the distributor to receive an electrical impulse in proper sequence. When the primary circuit is broken, a high potential (up to 20,000 volts) is developed in the secondary winding and conducted to the appropriate spark plug.

Spark plug

The spark plug is an important component of the ignition system and is the one that must operate under the most severe conditions. Because it is exposed to combustion-chamber temperatures and pressures and contaminating products of combustion, it requires more service attention and is usually the shortest-lived component of the gasoline engine. It consists of a steel shell threaded to fit a standard 14-millimetre hole in the cylinder head. A copper gasket insures a gastight fit between cylinder head and plug. A fused ceramic insulating element is molded into the plug body and the steel centre electrode passes through the insulator up to the connector to which the high-voltage lead from the distributor is attached. The other electrode is welded to the metal body of the plug, which is grounded to the cylinder head.

It is essential that the spark gap be as specified for the particular engine. Gauges are available to aid in making this adjustment by bending the ground electrode as required. Manufacturers specify gaps ranging from 0.508 to 1.016 millimetres between the centre electrode and the ground electrode. If the plug gap is too large, the possibility of misfiring increases. If the gap is too small, the spark will not be sufficiently intense. Gap growth from erosion of the electrodes may be corrected. The high voltage for the spark plug may also be produced by a capacitor discharge ignition system. Such a system consists of a source of 250 to 300 volts direct-current power applied to a storage capacitor, a device for storing an electric charge.

Capacitor ignition system

A lead from the capacitor goes to one side of the spark coil primary through cam-actuated breaker points or an electronic switching device. At the instant this switching device establishes a contact, the capacitor discharges through the primary of the spark coil and an instantaneous high voltage is delivered to the distributor and thence to the spark plug.

The capacitor discharge system stem provides a more intense spark, thus improving starting a cold or flooded engine. It continues to fire the plugs when they are fouled by carbon or other deposits or when the spark gap has widened because of erosion of the points. Other notable advantages include increased spark plug life, improved firing over a wider speed range, and better moisture tolerance.

A magneto is a fixed-magnet, alternating-current generator designed to generate sufficient voltage to fire the spark plugs. A high-tension magneto is entirely self-contained and requires only spark plugs, wires, and switches to do what is required in meeting ignition requirements.

Carburetor. The gasoline carburetor is a device that introduces fuel into the air stream as it flows into the engine. A simple carburetor is shown diagrammatically in Figure 24. Gasoline is maintained in the float chamber by the float-actuated valve at a level slightly below the outlet of the jet. Air flows downward through the throat, past the throttle valve, and into the intake manifold. A throat is formed by the reduced diameter, and acceleration of the air through this smaller passage causes a decrease in pressure proportional to the amount of air flowing. This decrease in throat pressure results in fuel flow from the jet into the air stream. Any increase in air flow caused by change in engine speed or throttle position increases the pressure differential acting on the fuel and causes more fuel to flow.

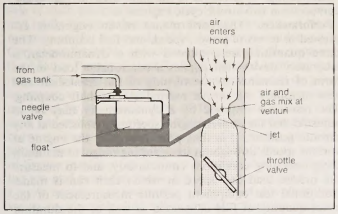

Figure 24: A simple carburetor.

The volume ratio of air to fuel established by the throat and fuel jet sizes will be maintained with increased flow, but the weight of fuel per kilogram (or pound) of air increases because the air expands to a lower density as the throat pressure decreases. This enriching tendency necessitates the inclusion of a compensating device in a practical carburetor. Carburetor design is further complicated by the need for an enriching device to provide a maximum-power ratio at full throttle, a choke to facilitate starting a cold engine, an idling system to provide the special needs of light-load operation, and an accelerating device to supply additional fuel while the throttle is being opened.

Fuel injection. Gasoline-injection systems in which the fuel is forcefully injected into the cylinder by a pump were available for airplane engines before World War II and were extensively used then in aircraft. The performance of engines with such equipment was excellent, but the much greater cost of fuel-injection systems compared with that of carburetors limited their application.

The above-mentioned form of fuel preparation is termed cylinder-head injection. Such a system, employed in stratified-charge engines, involves the injection of fuel directly into each cylinder under high pressure. It is well-suited for this type of engine, which is designed to permit operation under very fuel-lean conditions. Examples of stratified engines include the divided-chamber, axially stratified-charge, and direct-injection varieties (Figure 25).

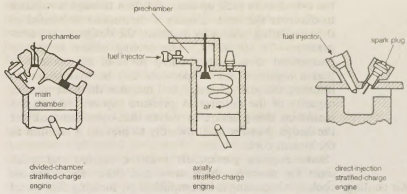

Figure 25: Stratified-charge engine design.
From R.A. Meyers (ed.), *Encyclopedia of Physical Science and Technology*, vol 6 (1987), Academic Press, Inc.

Efforts to simplify and lower the cost of fuel-injection equipment without impairing performance have yielded multicylinder pumps that can compete in cost with four-barrel carburetors. Gasoline-injection equipment may consist of distributor systems employing a single pump for all of the cylinders, or multipumps.

Advantages of fuel injection

The principal advantages of gasoline injection over carburetors are improved fuel economy because of more accurate fuel and air proportioning, greater power because of the elimination of fuel heating, elimination of inlet icing, and more uniform and direct delivery of fuel load to the cylinders.

Supercharger. The efficiency of the charging process in an automotive engine usually rises to a peak of slightly more than 80 percent at about half the rated speed of the engine and then decreases considerably at higher speed. This change in air charge per cycle with engine speed is reflected in proportionate changes in the torque, or turning effort, applied to the crankshaft and causes the power that the engine can deliver at full throttle to reach a maximum as engine speed increases. At speeds above this peaking speed, the air charge introduced per cycle falls off so rapidly that less power is developed than at lower speeds. The inability of the engine to draw in a full charge of fresh air at high speeds limits the power output of the engine.

Supercharging overcomes this disadvantage by the use of a pump or blower to raise the pressure of the air supplied to the cylinders, increasing the weight of charge. The loss in power suffered by unsupercharged engines at high altitudes can be largely restored; it is also possible to more than double the power of an engine by supercharging. Increased charge density and temperature, resulting from supercharging, increase the tendency for combustion knock or roughness in the spark-ignition engine and thus necessitates an undesirable decrease in compression ratio or the use of an antiknock fuel.

Turbocharger

The supercharging blower may be geared to the crankshaft, in which case the power consumed in driving it is added to the friction loss of the engine. A turbocharger employs a gas turbine operated by the exhaust gases to drive a centrifugal blower. The turbocharged engine not only gains increased power capacity but also operates at improved fuel economy. Airplane engines are usually supercharged both by geared blowers and by turbochargers to provide the large pumping capacity needed at high altitude.

Since compressing air prior to introducing it into the cylinder increases the charge-air temperature, the mass of air that can be introduced into the engine is less than that which would be possible if the compressed air were at ambient temperature. Consequently, engine charge-air coolers, commonly referred to as either intercoolers or aftercoolers, are used to reduce the temperature of the charge air. Both air-to-coolant and air-to-air type coolers are available.

Cooling system. The cylinders of internal-combustion engines require cooling because of the inability of the engine to convert all of the energy released by combustion into useful work. Liquid cooling is employed in most gasoline engines, whether the engines are for use in automobiles or elsewhere. The liquid is circulated around

the cylinders to pick up heat and then through a radiator to dissipate the heat. Usually a thermostat is located in the circulating system to maintain the design jacket temperature—71° to 82° C. The cooling system is usually pressurized to raise the boiling point of the coolant so that a higher outlet temperature can be maintained to improve thermal efficiency and increase the heat transfer capacity of the radiator. A pressure cap on the radiator maintains this pressure by valves that open outwardly at the design pressure and inwardly to prevent a vacuum as the system cools.

Air cooling

Some engines, particularly aviation engines and small units for mowers, chain saws, and other tools, are air cooled. Air cooling is accomplished by forming thin metal fins on the exterior surfaces of the cylinders to increase the rate of heat transfer by exposing more metal surface to the cooling air. Air is forced to flow rapidly through the spaces between the fins by ducting air toward the engine.

Lubrication system. Lubrication is employed to reduce friction by interposing a film between rubbing parts. The lubrication system must continuously replace the films.

The lubricants commonly employed are refined from crude oil after the fuels have been removed. Their viscosities must be appropriate for each engine and the oil must be suitable for the severity of the operating conditions. Oils are improved with additives that reduce oxidation, inhibit corrosion, and act as detergents to disperse deposit-forming gums and solid contaminants. Various systems of numbers are used to designate oil viscosity; the lower the number, the lighter the body of the oil. Certain oils contain additives that oppose their change in viscosity between the winter and summer.

Oil filters, if regularly serviced, can remove solid contaminants from crankcase oil, but chemical reactions may form liquids that are corrosive and damaging. Depletion of the additives also limits the useful life of lubricating oils.

The lubrication system is fed by the oil sump that forms the lower enclosure of the engine. Oil is taken from the sump by a pump, usually of the gear type, and delivered under pressure to a system of passages or channels drilled through the engine. In some instances a so-called full-flow filter runs the length of the engine between the pump and the main oil passage. In other engines bypass filters continuously bleed off a small quantity of oil and return the filtered oil to the sump.

Oil is supplied under pressure to crankshaft and camshaft main bearings. Adjacent crank throws are drilled to enable the oil to flow from the supply at the main bearings to the crankpins. Leaking oil from all of the crankshaft bearings is sprayed on the cylinder walls, cams, and up into the pistons to lubricate the piston pins. Additional passages intersect the cam-follower openings and supply oil to hydraulic valve lifters when used. A spring-loaded pressure-relief valve maintains the pressure at the proper level.

Exhaust system. Exhaust gases from an internal-combustion engine are passed through a muffler to suppress audible vibrations. When the exhaust valve opens, the pressure in the engine causes an initial gas outflow at explosive velocity. Successive discharges from the cylinders set up pressure pulsations that produce a sharp barking sound. The muffler damps out or absorbs these pulsations so that the gases leave the outlet as a relatively smooth, quiet stream.

Mufflers of early design contained sets of baffles that reversed the flow of the gases or otherwise caused them to follow devious paths so that interference between the pressure waves reduced the pulsations. The mufflers most commonly used in modern motor vehicles employ resonating chambers connected to the passages through which the gases flow. Gas vibrations are set up in each of these chambers at the fundamental frequency determined by its dimensions. These vibrations cancel or absorb those present in the exhaust stream of about the same frequency. Several such chambers, each tuned to one of the predominant frequencies present in the exhaust stream, effectively reduce noise.

Emission control

Emission control devices for reducing air pollution are added to the exhaust system. Beds of a suitable catalyst (a material for promoting desirable reactions) are placed in a mufflerlike chamber to reduce unburned hydrocarbons, carbon monoxide, and, in some instances, nitrogen oxides in the exhaust output. This device, called the catalytic converter, is used in conjunction with various other kinds of emission control systems.

The reactor system for controlling emission is composed of a belt-driven air compressor connected to small nozzles installed in the exhaust manifold facing the outlet from each exhaust valve. A small jet of air is thus directed toward the red-hot outflowing combustion products to provide oxygen to consume the hydrocarbons and carbon monoxide.

Fuels. Gasoline was originally considered dangerous and was discarded and destroyed at early refineries, which were manufacturing kerosene for lamps. As the gasoline engine developed, gasoline and the engine were harmonized to attain the best possible matching of characteristics. The most important properties of gasoline are its volatility and antiknock quality. Volatility is a measure of the ease of vaporization of gasoline in the carburetor.

Volatility and antiknock quality

To suit the needs of a modern engine a gasoline must have the volatility for which the fuel system of the engine was designed and antiknock quality sufficient to avoid knock under normal operation. Although other specifications must also be met, volatility and knock rating are the most important. The size and structural arrangement of the molecules principally determine the knocking tendency of a gasoline as well as its volatility.

Tetraethyl lead, added to gasolines for many years to improve antiknock fueling, has been found to contaminate the exhaust gases with poisonous lead oxides, and the practice is ending. Lower compression ratios and improved combustion-chamber designs are eliminating the need for extremely high antiknock gasolines.

Lubricating oil is added to gasoline used in crankcase-compression two-stroke cycle engines.

Performance. The performance of an engine is expressed in terms of power, speed, and fuel economy. The three quantities are evaluated with a dynamometer, a laboratory device that applies a controllable load in the form of resistance to the turning of the crankshaft and also measures the torque exerted at the shaft coupling. The resistance imposed by a dynamometer may be so adjusted that the desired engine speed is established at any throttle position. It is thus possible to run the engine at various speeds throughout its operating range, to maintain these operating conditions continuously, and to measure the precise load and speed at which each run is made. Additional test equipment permits measurement of the exact quantity of fuel consumed as well as the duration of the runs. From these data the power–speed–economy relationships can be calculated and performance plotted.

Power measurements

The power produced by an engine is, as explained earlier, expressed in horsepower. When the power developed is measured by means of a dynamometer or similar braking device, it is called brake horsepower. This is the power actually delivered by the engine and is therefore the capacity of the engine. The power developed in the combustion chambers of the engine is greater than the delivered power because of friction and other mechanical losses. This power loss, called the friction horsepower, can be evaluated by "motoring" the engine (driving it in a forward direction) with a suitable dynamometer when no fuel is being burned. The power developed in the cylinder can then be found by adding the friction horsepower to the brake horsepower. This quantity is the indicated horsepower of the engine, so called from an instrument known as the engine indicator, which is used to measure the pressure on the piston and thus calculate the power developed in the cylinder.

Mechanical efficiency is defined as brake horsepower in percent of indicated horsepower and is usually between 70 percent and 90 percent within the normal operating speed range.

A quantity called brake mean effective pressure is obtained by multiplying the mean effective pressure of an engine by its mechanical efficiency. This is a commonly used index expressing the ability of the engine, per unit of cylinder bore, to develop useful pressure in the cylinders

and delivery power. If the power delivered is increased by any change other than an increase in speed or cylinder dimensions, its brake mean effective pressure increases proportionately.

Applications. Gasoline engines can be built to meet the requirements of practically any conceivable power-plant application. In some instances, however, other kinds of engines or electric motors have certain advantages. The important applications for which the gasoline engine is most likely to be chosen in preference to other types are in the areas of passenger automobiles, small trucks and buses, aircraft, outboard and small inboard marine units, moderate-sized stationary pumping, lighting plant, machine tool and similar installations, and power tools.

Development of gasoline engines. While attempts to devise heat engines were made in ancient times, the steam engine of the 18th century was the first successful type. The internal-combustion engine, which followed in the 19th century as an improvement over the steam engine for many applications, cannot be attributed to any single inventor. The piston, thought to date as far back as 150 BC, was used by metalworkers in pumps for blowing air. The piston (and cylinder) was basic to the steam engine, which brought the component to a high state of efficiency. The steam engine, however, suffered from low thermal efficiency, great weight and bulk, and inconvenience of operation, all of which were primarily traceable to the necessity of burning the fuel in a furnace separate from the engine. It became evident that a self-contained power unit was desirable.

Early use of the piston

As early as the 17th century, several experimenters first tried to use hot gaseous products to operate pumps. By 1820 an engine was built in England in which hydrogen–air mixtures were exploded in a chamber. The chamber was then cooled to create a vacuum acting on a piston. The sale of such gas engines began in 1823. They were heavy and crude but contained many essential elements of later, more successful devices. In 1824 the French engineer Sadi Carnot published his now classic pamphlet "Reflections on the Motive Power of Heat," which outlined fundamental internal-combustion theory. Over the next several decades inventors and engineers built engines that used pressure produced by the combustion of fuels rather than a vacuum and engines in which the fuel was compressed before burning. None of them succeeded in developing an operational system, however. Finally, in 1860 Étienne Lenoir of France marketed an engine that operated on illuminating gas and provided reasonably satisfactory service. The Lenoir engine was essentially a converted double-acting steam engine with slide valves for admitting gas and air and for discharging exhaust products. Although the Lenoir engine developed little power and utilized only about 4 percent of the energy in the fuel, hundreds of these devices were in use in France and Britain within five years. They were used for powering water pumps and printing presses and for completing certain other tasks that required only limited power output.

The ideal operating cycle

A major theoretical advance occurred with the publication in 1862 of a description of the ideal operating cycle of an internal-combustion engine. The author, the French engineer Alphonse Beau de Rochas, laid down the following conditions as necessary for optimum efficiency: maximum cylinder volume with minimum cooling surface, maximum rapidity of expansion, maximum ratio of expansion, and maximum pressure of the ignited charge. He described the required sequence of operations as (1) suction during an entire outstroke of the piston, (2) compression during the following instroke, (3) ignition of the charge at dead centre and expansion during the next outstroke (the power stroke), and (4) expulsion of the burned gases during the next instroke. The engine Beau de Rochas described thus had a four-stroke cycle, in contrast to the two-stroke cycle (intake-ignition and power-exhaust) of the Lenoir engine. Beau de Rochas never built his engine, and no four-stroke engine appeared for more than a decade. Finally in 1876 the German engineer Nikolaus A. Otto built an internal-combustion unit based on Beau de Rochas's principle. (Otto's firm, Otto and Langen, had produced and marketed an improved two-stroke engine several years earlier.) The four-stroke Otto engine was an immediate success. In spite of its great weight and poor economy, nearly 50,000 engines with a combined capacity of about 200,000 horsepower were sold in 17 years, followed by the rapid development of a wide variety of engines of the same type. Manufacture of the Otto engine in the United States began in 1878, following the grant to Otto of a U.S. patent in 1877.

The Otto engine

Eight years later Gottlieb Daimler and Wilhelm Maybach, former associates of Otto, developed the first successful high-speed four-stroke engine and invented a carburetor that made it possible to use gasoline for fuel. They employed their engine to power a bicycle (perhaps the world's first motorcycle) and later a four-wheeled carriage. At about the same time, another German mechanical engineer, Carl Benz, built a one-cylinder gasoline engine to power what is often considered the first practical automobile. The engines built by Daimler and Benz were fundamentally the same as today's basic gasoline engine. For information about subsequent enhancements and advances, see TRANSFORTATION: *Modern automotive systems*. (O.C.C./C.L.P.II)

DIESEL ENGINES

General characteristics. The diesel engine is an intermittent-combustion piston–cylinder device. It operates as either a two-stroke or four-stroke cycle (see *Gasoline engines* above); however, unlike the spark-ignition engine, the diesel engine induces only air into the combustion chamber on its intake stroke. The air is heated as compression occurs during the compression stroke. Diesel engines are typically constructed with compression ratios in the range 14:1 to 22:1. Both two-stroke and four-stroke engine designs can be found among engines with bores (cylinder diameters) less than 600 millimetres. Engines with bores of greater than 600 millimetres are almost exclusively two-stroke cycle systems.

The diesel engine gains its energy by burning fuel injected or sprayed into the compressed, hot air charge within the cylinder. The air must be heated to a temperature greater than the temperature at which the injected fuel can ignite. Fuel sprayed into air that has a temperature higher than the "auto-ignition" temperature of the fuel spontaneously reacts with the oxygen in the air and burns. Air temperatures are typically in excess of 526° C; however, at engine start-up, supplemental heating of the cylinders is usually required, since the temperature of the air within the cylinders is determined by both the engine's compression ratio and its current operating temperature. Diesel engines are sometimes called compression-ignition engines because initiation of combustion relies on air heated by compression rather than on an electric spark.

Ignition by compression of air charge

In a diesel engine, fuel is introduced as the piston approaches the top dead centre of its stroke (see *Gasoline engines* above). The fuel is introduced under high pressure either into a precombustion chamber (Figure 26) or directly into the piston–cylinder combustion chamber. With the exception of small, high-speed systems, diesel engines use direct injection.

Direct injection

Diesel-engine fuel-injection systems are typically designed to provide injection pressures in the range of seven to 70 megapascals (1,000 to 10,000 pounds per square inch). There are, however, a few higher pressure systems.

Precise control of fuel injection is critical to the performance of a diesel engine. Since the entire combustion process is controlled by fuel injection, injection must begin at the correct piston position (*i.e.*, crank angle). At first, the fuel is burned in nearly a constant-volume process while the piston is near top dead centre. As the piston moves away from this position, fuel injection is continued, and the combustion process then appears as a nearly constant-pressure process.

The combustion process in a diesel engine is heterogeneous—that is to say, the fuel and air are not premixed prior to initiation of combustion. Consequently, rapid vaporization and mixing of fuel in air is very important to thorough burning of the injected fuel. This places much emphasis on injector nozzle design, especially in direct-injection engines.

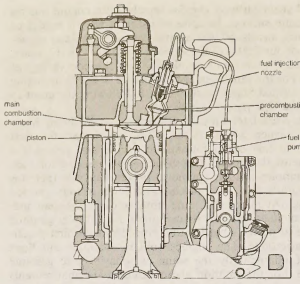

Figure 26: Diesel engine equipped with a precombustion chamber.

From H.A. Sorensen, *Energy Conversion Systems*, copyright © 1983 by John Wiley & Sons, Inc., reprinted by permission of John Wiley & Sons, Inc.

Engine work is obtained during the power stroke. The power stroke includes both the constant-pressure process during combustion and the expansion of the hot products of combustion after fuel injection ceases.

Diesel engines are often turbocharged and aftercooled (see *Supercharger* above). Addition of a turbocharger and aftercooler can enhance the performance of a diesel engine both in terms of power and efficiency.

High efficiency of diesel engines

The most outstanding feature of the diesel engine is its efficiency. By compressing air, rather than using an air–fuel mixture, the diesel engine is not limited by the preignition problems that plague high-compression spark-ignition engines. Thus higher compression ratios can be achieved with diesel engines than with the spark-ignition variety; commensurately, higher theoretical cycle efficiencies, when compared to the latter, can often be realized. It should be noted that for a given compression ratio, the theoretical efficiency of the spark-ignition engine is greater than that of the compression-ignition engine; however, in practice, it is possible to operate compression-ignition engines at compression ratios high enough to produce efficiencies greater than those attainable with spark-ignition systems. Furthermore, diesel engines do not rely on throttling the intake mixture to control power. As such, the idling and reduced power efficiency of the diesel is far superior to that of the spark-ignition engine.

High pollutant emissions

The principal drawback of diesel engines is their emission of air pollutants. These engines typically discharge high levels of particulate matter (soot), reactive nitrogen compounds (commonly designated NO_x), and odour compared to spark-ignition engines. Consequently, in the small engine category (see below), consumer acceptance is low.

Major types of diesel engines. There are three basic size groups of diesel engines based on power—namely, small, medium, and large. The small engines have power output values of less than 188 kilowatts, or 252 horsepower. This is the most commonly produced diesel-engine type. These engines are used in automobiles, light trucks, and some agricultural and construction applications, and as small stationary electrical power generators (such as those on pleasure craft) and as mechanical drives. They are typically direct-injection, in-line, four- or six-cylinder engines. Many are turbocharged with aftercoolers.

Medium engines have power capacities ranging from 188 to 750 kilowatts, or 252 to 1,006 horsepower. The majority of these engines are used in heavy-duty trucks (those of the class 6, 7, and 8 variety). They are usually direct-injection, in-line, six-cylinder turbocharged/aftercooled engines. Some V-8 and V-12 engines also belong to this size group.

Large diesel engines have power ratings in excess of 750 kilowatts. These unique engines are used for marine, locomotive, and mechanical drive applications and for electrical power generation. In most cases, they are direct-injection, turbocharged/aftercooled systems. They may operate at as low as 500 revolutions per minute when good reliability and durability are critical.

Engine structure and components. As noted earlier, diesel engines are designed to operate on either the two- or four-stroke cycle. In the typical four-stroke-cycle engine (Figure 27), the intake and exhaust valves and the fuel-injection nozzle are located in the cylinder head. Often dual valve arrangements, two intake and two exhaust valves, are employed.

Dual valve arrangement

Use of the two-stroke cycle can eliminate the need for one or both valves in the engine design. Scavenging and intake air is usually provided through ports in the cylinder liner. Exhaust can be either through valves located in the cylinder head or through ports in the cylinder liner. Engine construction is simplified when using a port design instead of one requiring exhaust valves.

Diesel engine starting. A diesel engine is started by driving it from some external power source until conditions have been established under which the engine can run by its own power. The most positive starting method is by admitting air at about 1.7 to nearly 2.4 megapascals to each of the cylinders in turn on their normal firing stroke. The compressed air becomes heated sufficiently to ignite the fuel. Other starting methods involve auxiliary equipment and include admitting blasts of compressed air to an air-activated motor geared to rotate a large engine's flywheel; supplying electric current to an electric starting motor, similarly geared to the engine flywheel; or by means of a small gasoline engine geared to the engine flywheel. The selection of the most suitable starting method depends on the physical size of the engine to be started, the nature of the connected load, and whether or not the load can be disconnected during starting.

Distillates composed of heavy hydrocarbons

Fuel for diesels. Petroleum products normally used as fuel for diesel engines are distillates composed of heavy hydrocarbons, with at least 12 to 16 carbon atoms per molecule. These heavier distillates are taken from crude oil after the more volatile portions used in gasoline are removed. The boiling points of these heavier distillates range from 177° to 343° C. Thus, their evaporation temperature is much higher than that of gasoline, which has fewer carbon atoms per molecule. Specifications for diesel fuels published in 1970 listed three grades: the first was a volatile distillate recommended for high-speed engines with frequent and wide variations in load and speed; the second, a distillate for high-speed engines in services with high loads and uniform speeds; and the third, a fuel for low- and medium-speed engines in service with sustained loads.

Water and sediment in fuels can be harmful to engine operation; clean fuel is essential to efficient injection systems. Fuels with a high carbon residue can be handled best by engines of low-speed rotation. The same applies to those with high ash and sulfur content. The cetane number, which defines the ignition quality of a fuel, is ascertained by adjusting a mixture of cetane and alpha-methyl-naphthalene until it has the same ignition quality as the fuel being tested. The percentage of cetane in this mixture is then the cetane number of the fuel under test. For the first two grades of diesel fuel described above, the minimum cetane number is 40; for the third grade, the minimum is 30, representing 30 percent cetane in the fuel.

Development of diesel engines. *Early work.* Rudolf Diesel, a German engineer, conceived the idea for the

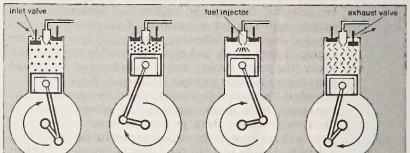

Figure 27: *Four-stroke diesel engine.*
The sequence of cycle events is shown here.

engine that now bears his name after seeking a device to increase the efficiency of the Otto engine (see *Development of gasoline engines* above). Diesel realized that the electric ignition process of the gasoline engine could be eliminated if, during the compression stroke of a piston–cylinder device, compression could heat air to a temperature higher than the auto-ignition temperature of a given fuel. Diesel proposed such a cycle in his patents of 1892 and 1893.

Originally, either powdered coal or liquid petroleum was proposed as fuel. Diesel saw powdered coal, a by-product of the Saar coal mines, as a readily available fuel. Compressed air was to be used to introduce coal dust into the engine cylinder; however, controlling the rate of coal injection was difficult, and after the experimental engine was destroyed by an explosion, Diesel turned to liquid petroleum. He continued to introduce the fuel into the engine with compressed air.

First commercial diesel engine

The first commercial engine built on Diesel's patents was installed in St. Louis, Mo., by Adolphus Busch, a brewer who had seen one on display at an exposition in Munich and had purchased a license from Diesel for the manufacture and sale of the engine in the United States and Canada. The engine operated successfully for years and was the forerunner of the Busch–Sulzer engine that powered many submarines of the U.S. Navy in World War I. Another diesel engine used for the same purpose was the Nelseco, built by the New London Ship and Engine Company in Groton, Conn.

The diesel engine became the primary power plant for submarines during World War I. It was not only economical in the use of fuel but also proved reliable under wartime conditions. Diesel fuel, less volatile than gasoline, was more easily stored and handled.

At the end of the war many men who had operated diesels were looking for peacetime jobs. Manufacturers began to adapt diesels for the peacetime economy. One modification was the development of the so-called semidiesel that operated on a two-stroke cycle at a lower compression pressure and made use of a hot bulb or tube to ignite the fuel charge. These changes resulted in an engine less expensive to build and maintain.

Fuel-injection technology. One objectionable feature of the full diesel was the necessity of a high-pressure, injection air compressor. Not only was energy required to drive the air compressor, but the sudden expansion of the air compressed to 6.9 megapascals when it entered the cylinder in which the pressure was only about 3.4 to 4.1 megapascals resulted in a refrigerating effect that delayed ignition. Diesel had needed high-pressure air with which to introduce powdered coal into the cylinder; when liquid petroleum replaced powdered coal as fuel, a pump could be made to take the place of the high-pressure air compressor.

Substitution of pumps for air compressors

There were a number of ways in which a pump could be used. In England the Vickers Company used what was called the common-rail method, in which a battery of pumps maintained the fuel under pressure in a pipe running the length of the engine with leads to each cylinder. From this rail (or pipe) fuel-supply line, a series of injection valves admitted the fuel charge to each cylinder at the right point in its cycle. Another method employed cam-operated jerk, or plunger-type, pumps, to deliver fuel under momentarily high pressure to the injection valve of each cylinder at the right time.

The elimination of the injection air compressor was a step in the right direction, but there was yet another problem to be solved: the engine exhaust contained an excessive amount of smoke, even at outputs well within the horsepower rating of the engine and even though there was enough air in the cylinder to burn the fuel charge without leaving a discoloured exhaust that normally indicated overload. Engineers finally realized that the problem was that the momentarily high-pressure injection air exploding into the engine cylinder had diffused the fuel charge more efficiently than the substitute mechanical fuel nozzles were able to do, with the result that without the air compressor, the fuel had to search out the oxygen atoms to complete the combustion process, and since oxygen makes up only 20 percent of the air, each atom of fuel had only one chance in five of encountering an atom of oxygen. The result was improper burning of the fuel.

The usual design of a fuel-injection nozzle introduced the fuel into the cylinder in the form of a cone spray, with the vapour radiating from the nozzle, rather than in a stream or jet. Very little could be done to diffuse the fuel more thoroughly. Improved mixing had to be accomplished by imparting additional motion to the air, most commonly by induction-produced air swirls or a radial movement of the air, called squish, or both, from the outer edge of the piston toward the centre. Various methods have been employed to create this swirl and squish. Best results are apparently obtained when the air swirl bears a definite relation to the fuel-injection rate. Efficient utilization of the air within the cylinder demands a rotational velocity that causes the entrapped air to move continuously from one spray to the next during the injection period, without extreme subsidence between cycles.

Swirl or squish

Price's engine. In 1914 a young American engineer, William T. Price, began to experiment with an engine that would operate with a lower compression ratio than that of the diesel and at the same time would not require either hot bulbs or tubes. As soon as his experiments began to show promise, he applied for patents.

In Price's engine the selected compression pressure of nearly 1.4 megapascals did not provide a high enough temperature to ignite the fuel charge when starting. Ignition was accomplished by a fine wire coil in the combustion chamber. Nichrome wire was used for this because it could easily be heated to incandescence when an electric current was passed through it. The experimental engine had a single horizontal cylinder with a bore of 43 centimetres and a stroke (maximum piston movement) of 48 centimetres and operated at 257 revolutions per minute. Because the nichrome wire required frequent replacement, the compression pressure was raised to 2.4 megapascals, which did provide a temperature high enough for ignition when starting. Some of the fuel charge was injected before the end of the compression stroke in an effort to increase the cycle timing and to keep the nichrome wire glowing hot.

In the meantime many engines of the two-stroke cycle, semidiesel type were being installed. Some were used to produce electricity for small municipalities, while others were installed in water pumping plants. Many provided power for tugs, fishing boats, trawlers, and workboats.

In the early 1920s the General Electric Company suggested to the Ingersoll–Rand Company, for whom Price was working, that they cooperate in the building of a diesel-electric locomotive. At that time many of the locomotives in service were powered by gasoline engines. A diesel-electric locomotive with Price's engine was completed in 1924 and placed in service for switching purposes in New York City. The success of this locomotive resulted in orders from railroads, factories, and open-pit mines. The engine used in most of these installations was a six-cylinder, 25-centimetre bore, 30-centimetre stroke system, rated 300 brake horsepower at 600 revolutions and weighing 6,800 kilograms.

Diesel-electric locomotive

Subsequent developments and applications. Many diesel engines were purchased for marine propulsion. The diesels, however, normally rotated faster than was desirable for the propellers of large ships because the high speeds of the huge propellers tended to create hollowed-out areas within the water around the propeller (cavitation), with resultant loss of thrust. The problem did not exist, however, with smaller propellers, and diesel engines proved especially suitable for yachts, in which speed is desired. The problem was solved by utilizing a diesel-electric installation in which the engines were connected to direct-current generators that furnished the electricity to drive an electric motor connected to the ship's propeller. There were also many installations in which the diesel was connected either directly or through gears to the propeller. When diesel engines of larger horsepower and slower rotation speeds became available, they were installed in cargo and passenger ships.

The diesel engine became the predominant power plant for military equipment on the ground and at sea during World War II. Since then it has been adopted for

use in heavy construction machinery, high-powered farm tractors, and most large trucks and buses. Diesel engines also have been installed in hospitals, telephone exchanges, airports, and various other facilities to provide emergency power during electrical power outages. In addition, they have been used in automobiles, albeit on a limited scale. Although diesels provide better fuel economy than gasoline engines, they do not run as smoothly as the latter and emit higher levels of pollutants. (L.V.A./C.L.P.II)

GAS-TURBINE ENGINES

General characteristics. Although the term gas turbine literally refers only to a turbine that employs a gas as the working fluid, it is conventionally used to describe a complete internal-combustion engine consisting of at least a compressor, a combustion chamber, and a turbine. Useful work or propulsive thrust can be obtained from the engine. It may drive a generator, pump, or propeller or, in the case of a pure jet aircraft engine, develop thrust by accelerating the turbine exhaust flow through a nozzle. Large amounts of power can be produced by a gas-turbine engine which, for the same output, is much smaller and lighter than a reciprocating internal-combustion engine. Reciprocating engines depend on the up-and-down motion of a piston, which must then be converted to rotary motion by a crankshaft arrangement, whereas a gas turbine delivers rotary shaft power directly. Although conceptually the gas-turbine engine is a simple device, the components for an efficient unit must be carefully designed and manufactured from costly materials because of the high temperatures and stresses encountered during operation. Thus, gas-turbine engine installations are usually limited to large units where they become cost-effective.

Differences between gas-turbine and reciprocating engines

Gas-turbine engine cycles. *Idealized simple open-cycle gas-turbine engine.* Most gas turbines operate on an open cycle in which air is taken from the atmosphere, compressed in a centrifugal or axial-flow compressor, and then fed into a combustion chamber. Here, fuel is added and burned at an essentially constant pressure with a portion of the air. Additional compressed air, which is bypassed around the burning section and then mixed with the very hot combustion gases, is required to keep the combustion chamber exit (in effect, the turbine inlet) temperature low enough to allow the turbine to operate continuously. If the unit is to produce shaft power, the combustion products (mostly air) are expanded in the turbine to atmospheric pressure. Most of the turbine output is required to operate the compressor; only the remainder is available to supply shaft work to a generator, pump, or other device. In a jet engine the turbine is designed to provide just enough output to drive the compressor and auxiliary devices. The stream of gas then leaves the turbine at an intermediate pressure (above local atmospheric pressure) and is fed through a nozzle to produce thrust. A simplified schematic for a gas turbine engine is given in Figure 28. Pressure–volume relations are also shown in the diagram.

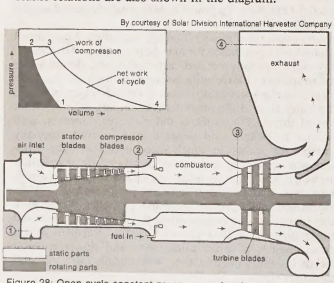

Figure 28: Open-cycle constant-pressure combustion-gas turbine. Circled numbers refer to points on the inset graph of the pressure-volume relationship during a working cycle (see text).

An idealized gas-turbine engine operating without any losses on this simple Brayton cycle is considered first. If, for example, air enters the compressor at 15° C and atmospheric pressure and is compressed to one megapascal, it then absorbs heat from the fuel at a constant pressure until the temperature reaches 1,100° C prior to expansion through the turbine back to atmospheric pressure. This idealized unit would require a turbine output of 1.68 kilowatts for each kilowatt of useful power with 0.68 kilowatt absorbed to drive the compressor. The thermal efficiency of the unit (net work produced divided by energy added through the fuel) would be 48 percent.

Brayton cycle

Actual simple open-cycle performance. If for a unit operating between the same pressure and temperature limits the compressor and the turbine are only 80 percent efficient (*i.e.,* the work of an ideal compressor equals 0.8 times the actual work, while the actual turbine output is 0.8 times the ideal output), the situation changes drastically even if all other components remain ideal. For every kilowatt of net power produced, the turbine must now produce 2.71 kilowatts while the compressor work becomes 1.71 kilowatts. The thermal efficiency drops to 25.9 percent. This illustrates the importance of highly efficient compressors and turbines. Historically it was the difficulty of designing efficient compressors, even more than efficient turbines, that delayed the development of the gas-turbine engine. Modern units can have compressor efficiencies of 86–88 percent and turbine efficiencies of 88–90 percent at design conditions.

Efficiency and power output can be increased by raising the turbine-inlet temperature. All materials lose strength at very high temperatures, however, and since turbine blades travel at high speeds and are subject to severe centrifugal stresses, turbine-inlet temperatures above 1,100° C require special blade cooling. It can be shown that for every maximum turbine-inlet temperature there is also an optimum pressure ratio. Modern aircraft gas turbines with blade cooling operate at turbine-inlet temperatures above 1,370° C and at pressure ratios of about 30:1.

Increasing efficiency and power output

Intercooling, reheating, and regeneration. In aircraft gas-turbine engines attention must be paid to weight and diameter size. This does not permit the addition of more equipment to improve performance. Accordingly, commercial aircraft engines operate on the simple Brayton cycle idealized above. These limitations do not apply to stationary gas turbines where components may be added to increase efficiency. Improvements could include (1) decreasing compression work by intermediate cooling, (2) increasing turbine output by reheating after partial expansion, or (3) decreasing fuel consumption by regeneration.

The first improvement would involve compressing air at nearly constant temperature. Although this cannot be achieved in practice, it can be approximated by intercooling (*i.e.,* by compressing the air in two or more steps and water-cooling it between steps back to its initial temperature). Cooling decreases the volume of air to be handled and, with it, the compression work required.

The second improvement involves reheating the air after partial expansion through a high-pressure turbine in a second set of combustion chambers before feeding it into a low-pressure turbine for final expansion. This process is similar to the reheating used in a steam turbine.

Both approaches require considerable additional equipment and are used less frequently than the third improvement. Here, the hot exhaust gases from the turbine are passed through a heat exchanger, or regenerator, to increase the temperature of the air leaving the compressor prior to combustion. This reduces the amount of fuel needed to reach the desired turbine-inlet temperature. The increase in efficiency is, however, tied to a large increase in initial cost and will be economical only for units that are run almost continuously.

Use of regenerators

Major components of gas-turbine engines. *Compressor.* Early gas turbines employed centrifugal compressors, which are relatively simple and inexpensive. They are, however, limited to low pressure ratios and cannot match the efficiencies of modern axial-flow compressors. Accordingly, centrifugal compressors are used today primarily in small industrial units.

An axial-flow compressor is the reverse of a reaction turbine (see *Steam turbines* above). The blade passages, which look like twisted, highly curved airfoils, must exert a tangential force on the fluid with the pressures on one side of the blade higher than on the other. For subsonic flow, an increase in pressure requires the flow area to also increase, thus reducing the flow velocity between the blade passages and diffusing the flow. A typical compressor stage is shown schematically in Figure 29 with corresponding velocity diagrams. A simple passage flow interpretation, however, is not enough for design purposes. Here, a row of compressor blades must be viewed as a set of closely spaced, highly curved airfoil shapes with which airflow strongly interacts. There will not only be a rise in pressure along the blades but a variation between them as well. Flow friction, leakage, wakes produced by the previous sets of blades, and secondary circulation or swirl flows all contribute to losses in a real unit. Tests of stationary blade assemblies, known as cascades, can be performed in special wind tunnels, but actual blade arrangements in a rotating assembly require special test setups or rigs.

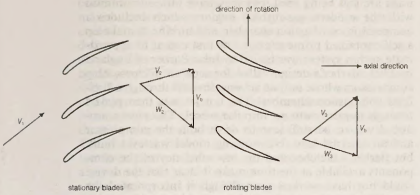

Figure 29: *Typical axial-flow compressor stage with velocity diagrams.*
Here, V is the absolute velocity of fluid, V_x is the blade velocity, and W is the velocity of fluid relative to the blade. Subscript 1 denotes entry into stationary blade (stator), subscript 2 signifies exit from stator or entry into rotor, and subscript 3 indicates exit from rotor.

Blades must be designed not only to have the correct aerodynamic shape but also to be light and not prone to critical vibrations. Recent advances in compressor (and turbine) blade design have been aided by extensive computer programs.

While moderately large expansion-pressure ratios can be achieved in a reaction-turbine stage, only relatively small pressure increases can be handled by a compressor stage—typically pressure ratios per stage of 1.35 or 1.4 to 1 in a modern design. Thus, compressors require more stages than turbines. If higher stage pressure ratios are attempted, the flow will tend to separate from the blades, leading to turbulence, reduced pressure rise, and a "stalling" of the compressor with a concurrent loss of engine power. Unfortunately, compressors are most efficient close to this so-called surge condition, where small disturbances can disrupt operation. It remains a major challenge to the designer to maintain high efficiency without stalling the compressor.

As the air is compressed, its volume decreases. Thus the annular passage area should also decrease if the through-flow velocity is to be kept nearly constant—*i.e.*, the blades have to become shorter at higher pressures. An optimum balance of blade-tip speeds and airflow velocities often requires that the rotational speed of the front, low-pressure end of the compressor be less than that of the high-pressure end. This is achieved in large aircraft gas turbines by "spooled" shafts where the shaft for the low-pressure end, driven by the low-pressure portion of the turbine, is running at a different speed within the hollow high-pressure compressor/turbine shaft, with each shaft having its own bearings. Both twin- and triple-spool engines have been developed.

Combustion chamber. Air leaving the compressor must first be slowed down and then split into two streams. The smaller stream is fed centrally into a region where atomized fuel is injected and burned with a flame held in place by a turbulence-generating obstruction. The larger, cooler stream is then fed into the chamber through holes along a "combustion liner" (a sort of shell) to reduce the overall temperature to a level suitable for the turbine inlet. Combustion can be carried out in a series of nearly cylindrical elements spaced around the circumference of the engine called cans, or in a single annular passage with fuel-injection nozzles at various circumferential positions. The difficulty of achieving nearly uniform exit-temperature distributions in a short aircraft combustion chamber can be alleviated in stationary applications by longer chambers with partial internal reversed flow.

Turbine. The turbine is normally based on the reaction principle with the hot gases expanding through up to eight stages using one- or two-spooled turbines. In a turbine driving an external load, part of the expansion frequently takes place in a high-pressure turbine that drives only the compressor while the remaining expansion takes place in a separate, "free" turbine connected to the load.

One- or two-spooled turbines

High-performance aircraft engines usually employ multiple spools. A recent large aircraft-engine design operating with an overall pressure ratio of 30.5:1 uses two high-pressure turbine stages to drive 11 high-pressure compressor stages on the outer spool, rotating at 9,860 revolutions per minute, while four low-pressure turbine stages drive the fan for the bypass air as well as four additional low-pressure compressor stages through the inner spool turning at 3,600 revolutions per minute (see below). For stationary units, a total of three to five total turbine stages is more typical.

High temperatures at the turbine inlet and high centrifugal blade stresses necessitate the use of special metallic alloys for the turbine blades. (Such alloys are sometimes grown as single crystals.) Blades subject to very high temperatures also must be cooled by colder air drawn directly from the compressor and fed through internal passages. Two processes are currently used: (1) jet impingement on the inside of hollow blades, and (2) bleeding of air through tiny holes to form a cooling blanket over the outside of the blades.

Control and start-up. In a gas-turbine engine driving an electric generator, the speed must be kept constant regardless of the electrical load. A decrease in load from the design maximum can be matched by burning less fuel while keeping the engine speed constant. Fuel flow reduction will lower the exit temperature of the combustion chamber and, with it, the enthalpy drop available to the turbine. Although this reduces the turbine efficiency slightly, it does not affect the compressor, which still handles the same amount of air. The foregoing method of control is substantially different from that of a steam turbine, where the mass flow rate has to be changed to match varying loads.

An aircraft gas-turbine engine is more difficult to control. The required thrust, and with it engine speed, may have to be changed as altitude and aircraft speed are altered. Higher altitudes lead to lower air-inlet temperatures and pressures and reduce the mass flow rate through the engine. Aircraft now use complex computer-driven controls to adjust engine speed and fuel flow while all critical conditions are monitored continuously.

For start-up, gas turbines require an external motor which may be either electric or, for stationary applications, a small diesel engine.

External motor for start-up

Other design considerations. Many other aspects enter into the design of a modern gas-turbine engine, of which only a few examples can be given. Much attention must be paid, especially in a multispool unit, to the design of all bearings, including the thrust bearings that absorb axial forces, and to the lubrication system. As an engine is started up and becomes hot, components elongate or "grow," thereby affecting passage clearances and seals. Other considerations include bleeding air from the compressor and ducting it for turbine-blade cooling or for driving accessories.

Applications. By far the most important use of gas turbines is in aviation, where they provide the motive power for jet propulsion. Because of the significance of this application and the diversity of modern jet engines, the

subject will be dealt with at length in a separate section of the article. The present discussion will touch on the use of gas turbines in electric power generation and in certain industrial processes, as well as consider their role in marine, locomotive, and automotive propulsion.

Electric power generation. In the field of electric power generation, gas turbines must compete with steam turbines in large central power stations and with diesel engines in smaller plants. Even though the initial cost of a gas turbine is less than either alternative for moderately sized units, its inherent efficiency is also lower. Yet, a gas-turbine unit requires less space, and it can be placed on-line within minutes, as opposed to a steam unit that requires many hours for start-up. As a consequence, gas-turbine engines have been widely used as medium-sized "peak load" plants to run intermittently during short durations of high power demand on an electric system. In this case, initial costs, rather than fuel charges, become the prime consideration.

Advantages of a gas turbine

Early commercial stationary plants employed aircraft units operating at reduced turbine-inlet temperatures. The high rotational speed of aircraft turbines required special gearing to drive electric generators. More recently, special units have been designed for direct operation (in the United States) at 3,600 revolutions per minute. Units in sizes up to 200,000 kilowatts have been built, although the majority of installations are less than 100,000 kilowatts. These turbines have operated up to 6,000 hours per year on either liquid fuels or natural gas. Typical turbine-inlet temperatures for large units range from about 980° to 1,260° C with turbine blade cooling used at the higher temperatures.

Efficiency can be improved by adding a regenerator to exploit the high turbine exhaust temperatures (typically about 480° to 590° C). Alternatively, if the gas turbine serves as a peak-load unit for a continuously running steam power plant, the hot exhaust gases can be used to preheat by means of a heat exchanger the combustion air entering a steam boiler. A modern development involves feeding the gas turbine exhaust directly into a steam generator where additional fuel is burned, producing steam of moderate pressure for a steam turbine. An overall thermal efficiency of nearly 50 percent is claimed for these combined units, making them the most fuel-efficient power plants currently available.

Use as a peak-load unit for a steam power plant

Industrial uses. With sizes typically ranging from 1,000 to 50,000 horsepower, industrial gas-turbine engines can be used for many applications. These include driving compressors for pumping natural gas through pipelines, where a small part of the pumped gas serves as the fuel. Such units can be automated so that only occasional on-site supervision is required. A gas turbine can also be incorporated in an oil refining process called the Houdry process, in which pressurized air is passed over a catalyst to burn off accumulated carbon. The hot gases then drive a turbine directly without a combustion chamber. The turbine, in turn, drives a compressor to pressurize the air for the process. Small portable gas turbines with centrifugal compressors also have been used to operate pumps.

Marine propulsion. In this area of application, the gas-turbine engine has two advantages over steam- and diesel-driven plants: it is lightweight and compact. During the early 1970s a ship powered by a gas turbine capable of 20,000 horsepower was successfully tested at sea by the U.S. Navy over a period of more than 5,000 hours. Gas turbines were subsequently selected to power various new U.S. naval vessels.

Use in naval vessels

Locomotive propulsion. During the 1950s and '60s, manufacturers of locomotives built a number of vehicles powered by gas-turbine engines that use heavy oil. Although gas-turbine locomotives have had moderate success for long sustained runs, they have not been able to make significant inroads against diesel locomotives under normal running conditions, especially after increases in the relative cost of heavy fuel oils. Moreover, the inherent low efficiency of a simple open-cycle gas turbine becomes even worse at part-load or during idling when considerable fuel is needed to drive the compressor while producing little or no useful power.

Automotive propulsion. Gas-turbine engines were proposed for use in automobiles from the early 1960s. In spite of their small size and weight for a given power output and their low exhaust emissions compared to gasoline engines, the disadvantages of high manufacturing costs, low thermal efficiency, and poor part-load and idling performance have proven gas-turbine cars to be uneconomical and impractical.

Development of gas turbines. *Origins.* The earliest device for extracting rotary mechanical energy from a flowing gas stream was the windmill (see above). It was followed by the smokejack, first sketched by Leonardo da Vinci and subsequently described in detail by John Wilkins, an English clergyman, in 1648. This device consisted of a number of horizontal sails that were mounted on a vertical shaft and driven by the hot air rising from a chimney. With the aid of a simple gearing system, the smokejack was used to turn a roasting spit.

The smokejack

Various impulse and reaction air-turbine drives were developed during the 19th century. These made use of air, compressed externally by a reciprocating compressor, to drive rotary drills, saws, and other devices. Many such units are still being used, but they have little in common with the modern gas-turbine engine, which includes a compressor, combustion chamber, and turbine to make up a self-contained prime mover. The first patent to approximate such a system was issued to John Barber of England in 1791. Barber's design called for separate reciprocating compressors whose output air was directed through a fuel-fired combustion chamber. The hot jet was then played through nozzles onto an impulse wheel. The power produced was to be sufficient to drive both the compressor and an external load. No working model was ever built, but Barber's sketches and the low efficiency of the components available at the time make it clear that the device could not have worked even though it incorporated the essential components of today's gas-turbine engine.

Although many devices were subsequently proposed, the first significant advance was covered in an 1872 patent granted to F. Stolze of Germany. Dubbed the fire turbine, his machine consisted of a multistage, axial-flow air compressor that was mounted on the same shaft as a multistage, reaction turbine. Air from the compressor passed through a heat exchanger, where it was heated by the turbine exhaust gases before passing through a separately fired combustion chamber. The hot compressed air was then ducted to the turbine. Although Stolze's device anticipated almost every feature of a modern gas-turbine engine, both compressor and turbine lacked the necessary efficiencies to sustain operation at the limited turbine-inlet temperature possible at the time.

Developments of the early 20th century. The first successful gas turbine, built in Paris in 1903, consisted of a three-cylinder, multistage reciprocating compressor, a combustion chamber, and an impulse turbine. It operated in the following way: Air supplied by the compressor was burned in the combustion chamber with liquid fuel. The resulting gases were cooled somewhat by the injection of water and then fed to an impulse turbine. This system, which had a thermal efficiency of about 3 percent, demonstrated for the first time the feasibility of a practical gas-turbine engine.

First successful gas turbine

Two other devices with intermittent gas action, both developed at about the same time, deserve mention. A 10,000-revolutions-per-minute unit built in Paris in 1908 had four explosion chambers located on the periphery of a de Laval impulse turbine. Each chamber, containing air and fuel, was fired sequentially to provide a nearly continuous flow of high-temperature, high-pressure gases that were fed through nozzles to the turbine wheel. The momentary partial vacuum created by the hot gases rushing from the explosion chamber was used to draw in a new charge of air.

Of greater significance was the "explosion" turbine developed by Hans Holzwarth of Germany, whose initial experiments started in 1905. In this system, a compressor introduced a charge of air and fuel into a constant-volume combustion chamber. After ignition, the hot, high-pressure gas escaped through spring-loaded valves into nozzles directed against the blading of a turbine. The valves re-

mained open until the gas was discharged, at which point a fresh charge was brought into the combustion chamber. Since the pressure increase in the compressor was only about one-fourth of the maximum pressure reached after combustion, the unit could operate even though the compressor efficiency was low. Holzwarth and various collaborators continued to develop the explosion turbine for more than 30 years until it was eventually superseded by the modern gas-turbine engine.

To be successful, a steady-flow engine based on the ideas first proposed by Stolze depends not only on high efficiencies (more than 80 percent) for both the rotating compressor and the turbine but also on moderately high turbine-inlet temperatures. The first successful experimental gas turbine using both rotary compressors and turbines was built in 1903 by Aegidus Elling of Norway. In this machine, part of the air leaving a centrifugal compressor was bled off for external power use. The remainder, which was required to drive the turbine, passed through a combustion chamber and then through a steam generator where the hot gas was partially cooled. This combustion gas was cooled further (by steam injected into it) to 400° C, the maximum temperature that Elling's radial-inflow turbine could handle. The earliest operational turbine of this type delivered 11 horsepower. Many subsequent improvements led to another experimental Elling turbine, which by 1932 could produce 75 horsepower. It employed a compressor with 71-percent efficiency and a turbine with an efficiency of 82 percent operating at an inlet temperature of 550° C. Norway's industry, however, was unable to capitalize on these developments, and no commercial units were built. The first industrial success did not come until 1936, when the Swiss firm of Brown Boveri independently developed a gas turbine for the Houdry process (see above).

System featuring both a rotating compressor and a turbine

Also during the mid-1930s a group headed by Frank Whittle at the British Royal Aircraft Establishment (RAE) undertook efforts to design an efficient gas turbine for jet propulsion of aircraft. The unit produced by Whittle's group worked successfully during tests; it was determined that a pressure ratio of about 4 could be realized with a single centrifugal compressor running at roughly 17,000 revolutions per minute. Shortly after Whittle's achievement, another RAE group, led by A.A. Griffith and H. Constant, began developmental work on an axial-flow compressor. Axial-flow compressors, though much more complex and costly, were better suited for detailed blade-design analysis and could reach higher pressures and flow rates and, eventually, higher efficiencies than their centrifugal counterparts.

Independent parallel developments in Germany, initiated by Hans P. von Ohain working with the manufacturing firm of Ernst Heinkel, resulted in a fully operational jet aircraft engine that featured a single centrifugal compressor and a radial-inflow turbine. This engine was successfully tested in the world's first jet-powered airplane flight on Aug. 27, 1939. Subsequent German developments directed by Anselm Franz led to the Junkers Jumo 004 engine for the Messerschmitt Me-262 aircraft, which was first flown in 1942. In Germany as well as in Britain, the search for higher temperature materials and longer engine life was aided by experience gained in developing aircraft turbosuperchargers.

Use in military aircraft

Before the end of World War II gas-turbine jet engines built by Britain, Germany, and the United States were flown in combat aircraft. Within the next few decades both propeller-driven gas-turbine engines (turboprops) and pure jet engines developed rapidly, with the latter assuming an ever larger role as airplane speeds increased.

Recent trends. Because of the significant advances in gas-turbine engine design in the years following World War II, it was expected that such systems would become an important prime mover in many areas of application. However, the high cost of efficient compressors and turbines, coupled with the continued need for moderate turbine-inlet temperatures, have limited the adoption of gas-turbine engines. Their preeminence remains assured only in the field of aircraft propulsion for medium and large planes that operate at either subsonic or supersonic speeds. As for electric power generation, large central power plants that use steam or hydraulic turbines are expected to continue to predominate. The prospects appear bright, nonetheless, for medium-sized plants employing gas-turbine engines in combination with steam turbines. Further use of gas-turbine engines for peak power production is likely as well. These turbine engines also remain attractive for small and medium-sized, high-speed marine vessels and for certain industrial applications. (Fr.L.)

JET ENGINES

General characteristics. The prime mover of virtually all jet engines is a gas turbine. Variously called the core, gas producer, gasifier, or gas generator, the gas turbine converts the energy derived from the combustion of a liquid hydrocarbon fuel to mechanical energy in the form of a high-pressure, high-temperature airstream. This energy is then harnessed by what is termed the propulsor (*e.g.*, airplane propeller and helicopter rotor) to generate a thrust with which to propel the aircraft.

Principles of operation. *The prime mover.* The gas turbine operates on the Brayton cycle in which the working fluid is a continuous flow of air ingested into the engine's inlet (see *Gas-turbine engine cycles* above). As shown in Figure 30, the air is first compressed by a turbocompressor to a pressure ratio of typically 10 to 40 times the pressure of the inlet airstream. It then flows into a combustion chamber, where a steady stream of the hydrocarbon fuel, in the form of liquid spray droplets and vapour or both,

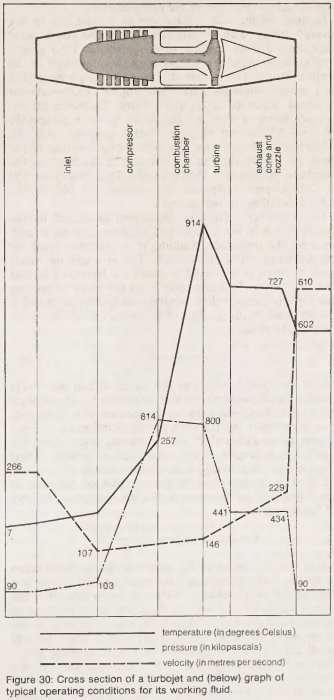

Figure 30: Cross section of a turbojet and (below) graph of typical operating conditions for its working fluid.

is introduced and burned at approximately constant pressure. This gives rise to a continuous stream of high-pressure combustion products whose average temperature is typically from 980° to 1,540° C or higher. This stream of gases flows through a turbine, which is linked by a torque shaft to the compressor and which extracts energy from the gas stream to drive the compressor. Because heat has been added to the working fluid at high pressure, the gas stream that exits from the gas generator after having been expanded through the turbine contains a considerable amount of surplus energy—*i.e.*, gas horsepower—by virtue of its high pressure, high temperature, and high velocity, which may be harnessed for propulsion purposes.

Gas horsepower

The heat released by burning a typical jet fuel in air is approximately 43,370 kilojoules per kilogram (18,650 British thermal units per pound) of fuel. If this process were 100 percent efficient, it would then produce a gas power for every unit of fuel flow of 7.45 horsepower/(pounds per hour), or 12 kilowatts/(kilograms per hour). In actual fact, certain practical thermodynamic limitations, which are a function of the peak gas temperature achieved in the cycle, restrict the efficiency of the process to about 40 percent of this ideal value. The peak pressure achieved in the cycle also affects the efficiency of energy generation. This implies that the lower limit of specific fuel consumption (SFC) for an engine producing gas horsepower is 0.336 (pound per hour)/horsepower, or 0.207 (kilogram per hour)/kilowatt. In actual practice, the SFC is even higher than this lower limit because of inefficiencies, losses, and leakages in the individual components of the prime mover.

Because weight and volume are at a premium in the overall design of an aircraft and because the power plant represents a large fraction of any aircraft's total weight and volume, these parameters must be minimized in the engine design. The airflow that passes through an engine is a representative measure of the engine's cross-sectional area and hence its weight and volume. Therefore, an important figure of merit for the prime mover is its specific power—the amount of power that it generates per unit of airflow. This quantity is a very strong function of the peak gas temperature in the core at the discharge of the combustion chamber. Modern engines generate from 150 to 250 horsepower/(pound per second), or 247 to 411 kilowatts/(kilogram per second).

Specific power

The propulsor. The gas horsepower generated by the prime mover in the form of hot, high-pressure gas is used to drive the propulsor, enabling it to generate thrust for propelling or lifting the aircraft. The principle on which such a thrust is produced is based on Newton's second law of motion. This law generalizes the observation that the force (F) required to accelerate a discrete mass (m) is proportional to the product of that mass and the acceleration (a). In effect,

$$F = ma = \frac{wa}{g},$$

where the mass is taken as the weight (w) of the object divided by the acceleration due to gravity (g) at the place where the object was weighed. In the case of a jet engine, one is generally dealing with the acceleration of a steady stream of air rather than with a discrete mass. Here, the equivalent statement of the second law of motion is that the force (F) required to increase the velocity of a stream of fluid is proportional to the product of the rate of mass flow (M) of the stream and the change in velocity of the stream,

$$F = M(V_j - V_0) = \frac{W(V_j - V_0)}{g},$$

where the inlet velocity (V_0) relative to the engine is taken to be the flight velocity and the discharge velocity (V_j) is the exhaust or jet velocity relative to the engine. W is the rate of weight flow of working fluid (*i.e.*, air or products of combustion) divided by the acceleration of gravity in the place where the weight flow is measured. The relatively small effect of the weight flow of fuel in creating a difference between the weight flow of the inlet and exhaust streams is intentionally disregarded.

One thereby infers that the components of a propulsor must exert a force F on the stream of air flowing through the propulsor if this device accelerates the airstream from the flight velocity V_0 to the discharge velocity V_j. The reaction to that force F is ultimately transmitted by the mounts of the propulsor to the aircraft as propulsive thrust.

There are two general approaches to converting gas horsepower to propulsive thrust. In one, a second turbine (*i.e.*, a low-pressure, or power, turbine) may be introduced into the engine flow path to extract additional mechanical power from the available gas horsepower. This mechanical power may then be used to drive an external propulsor, such as an airplane propeller or helicopter rotor. In this case, the thrust is developed in the propulsor as it energizes and accelerates the airflow through the propulsor—*i.e.*, an airstream separate from that flowing through the prime mover.

Use of a second turbine

In the second approach, the high-energy stream delivered by the prime mover may be fed directly to a jet nozzle, which accelerates the gas stream to a very high velocity as it leaves the engine, as is typified by the turbojet. In this case, the thrust is developed in the components of the prime mover as they energize the gas stream.

In other types of engines, such as the turbofan, thrust is generated by both approaches: A major part of the thrust is derived from the fan, which is powered by a low-pressure turbine and which energizes and accelerates the bypass stream (see below). The remaining part of the total thrust is derived from the core stream, which is exhausted through a jet nozzle.

Just as the prime mover is an imperfect device for converting the heat of fuel combustion to gas horsepower, so the propulsor is an imperfect device for converting the gas horsepower to propulsive thrust. There is generally a great deal of energy left in the high-temperature, high-velocity jet stream exiting from the propulsor that is not fully exploited for propulsion. The efficiency of a propulsor, propulsive efficiency η_p, is the portion of the available energy that is usefully applied in propelling the aircraft compared to the total energy of the jet stream. For the simple but representative case of the discharge airflow equal to the inlet gas flow, it is found that

Propulsive efficiency

$$\eta_p = \frac{2V_0}{V_j + V_0}.$$

Although the jet velocity V_j must be larger than the aircraft velocity V_0 to generate useful thrust, a large jet velocity that exceeds flight speed by a substantial margin can be very detrimental to propulsive efficiency. Maximum propulsive efficiency is approached when the jet velocity is almost equal to (but, of necessity, slightly higher than) the flight speed. This fundamental fact has given rise to a large variety of jet engines, each designed to generate a specific range of jet velocities that matches the range of flight speeds of the aircraft that it is supposed to power (see Figure 31).

The net assessment of the efficiency of a jet engine is the measurement of its rate of fuel consumption per unit of thrust generated (*e.g.*, in terms of pounds, or kilograms, per hour of fuel consumed per pounds, or kilograms, of thrust generated). There is no simple generalization of the value of specific fuel consumption of a thrust engine. It is

Specific fuel consumption

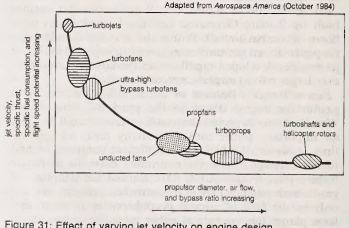

Figure 31: Effect of varying jet velocity on engine design and operation.

not only a strong function of the prime mover's efficiency (and hence its pressure ratio and peak-cycle temperature) but also of the propulsive efficiency of the propulsor (and hence of the engine type). It also is a strong function of the aircraft flight speed and the ambient temperature (which is in turn a strong function of altitude, season, and latitude).

Basic engine types. Achieving a high propulsive efficiency for a jet engine is dependent on designing it so that the exiting jet velocity is not greatly in excess of the flight speed. At the same time, the amount of thrust generated is proportional to that very same velocity excess that must be minimized. This set of restrictive requirements has led to the evolution of a large number of specialized variations of the basic turbojet engine, each tailored to achieve a balance of good fuel efficiency, low weight, and compact size for duty in some band of the flight speed–altitude–mission spectrum. There are two major general features characteristic of all the different engine types, however. First, in order to achieve a high propulsive efficiency, the jet velocity, or the velocity of the gas stream exiting the propulsor, is matched to the flight speed of the aircraft—slow aircraft have engines with low jet velocities and fast aircraft have engines with high jet velocities. Second, as a result of designing the jet velocity to match the flight speed, the size of the propulsor varies inversely with the flight speed of the aircraft—slow aircraft have very large propulsors, as, for example, the helicopter rotor—and the relative size of the propulsor decreases with increasing design flight speed—turboprop propellers are relatively small and turbofan fans even smaller.

Although the turbojet is the simplest jet engine and was invented and flown first among all the engine types, it seems useful to examine the entire spectrum of engines in the order of the flight-speed band in which they serve, starting with the slowest—namely, the turboshaft engine, which powers helicopters.

Turboshaft engines. The helicopter is designed to operate for substantial periods of time hovering at zero flight speed. Even in forward flight, helicopters rarely exceed 240 kilometres per hour or a Mach number of 0.22. (The Mach number is the ratio of the velocity of the aircraft to the speed of sound.) The principal propulsor is the helicopter rotor, which is driven by one or more turboshaft engines (Figure 32) in all modern helicopters of large size. As was previously noted, the propulsor is designed to give a very low discharge or jet velocity and is by the same token very large for a given size aircraft when compared to the propulsors of higher-speed aircraft. The prime mover of a helicopter is a core engine whose gas horsepower is extracted by a power turbine, which then drives the helicopter rotor via a speed-reducing (and combining) gearbox. The power turbine is usually located on a spool separate from the gas generator; thus its rotative speed and that of the helicopter rotor which it drives are independent of the rotative speed of the gas generator. This allows the rotor speed to be varied or kept constant independently of the gas-generator speed, which must be varied to modulate the amount of power generated.

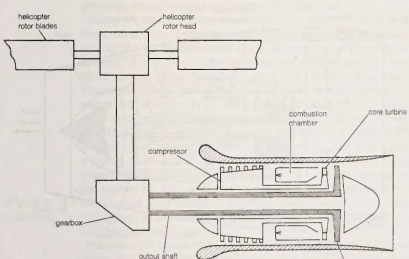

Figure 32: Turboshaft engine driving a helicopter rotor as propulsor.

Turboprops, propfans, and unducted fan engines. The turboprop is the power plant that occupies the next band of flight speeds in the flight spectrum, from a Mach number of 0.2 to 0.7. The propulsor is a propeller with a somewhat higher discharge, or jet velocity, than that of the helicopter rotor to match the flight speed, and it has a proportionately smaller area than the latter for a similarly sized aircraft. As shown in Figure 33, the prime mover is a turboshaft engine (very similar to the one that drives a helicopter rotor except for a different gearbox) designed to provide a somewhat higher rotative speed for the propeller, which turns faster than the helicopter rotor having a much larger diameter. The control mode of the turboprop also is somewhat different from that of a helicopter's turboshaft engine. In a helicopter the pilot calls for power by manipulating the pitch of the rotor blades (a greater pitch taking a bigger "bite" of air and so demanding more power to maintain rotative speed). The engine's control responds by increasing fuel to the engine to maintain output shaft speed. In a turboprop, the pilot calls for power by selecting fuel flow to the prime mover. The propeller control responds by varying propeller pitch to attain a greater "pull" while maintaining a preselected propeller rotative speed.

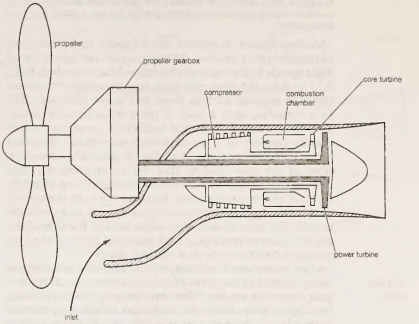

Figure 33: Turboprop engine driving a single rotation propeller as propulsor; tractor arrangement.

Trends in turboprop design

A recent trend in turboprop design has been the evolution of propellers for efficient operation at transonic flight speeds (those approximating the speed of sound), much higher than previously achieved—up to Mach numbers of 0.85. This usually involves a higher disk loading (*i.e.*, a higher discharge velocity from the propeller) in order to permit the use of a smaller diameter propeller. This trend has been accompanied by an increase in the number of blades in the propeller (from six to 12 instead of the more common two to four blades in lower-speed propellers). The blades are scimitar-shaped, with swept-back leading edges at the blade tips to accommodate the large Mach numbers encountered by the propeller tip at high rotative and flight speeds. Such high-speed propulsors are called propfans.

Another variation of the propulsor involves the application of two concentric propellers on the same centreline, driven by the same prime mover through a gearbox that causes each propeller to rotate in a direction opposite the other. Such counter-rotating propellers are capable of significantly higher propulsive efficiency and higher disk loading than conventional propellers.

Counter-rotating propellers

In most turboprop installations the prime mover is mounted on the wing, and the plane of the propeller is forward of the prime mover (the so-called tractor layout). Modern high-speed aircraft may find it more advantageous to mount the engine more toward the rear of the aircraft, with the plane of the propeller aft of the engine. These ar-

rangements are referred to as "pusher" layouts. A recently developed engine layout, identified as the unducted fan (or UDF; trademark), provides a set of very high-efficiency counter-rotating propeller blades, each blade mounted on one of either of two sets of counter-rotating low-pressure turbine stages and achieving all the advantages of the arrangement without the use of a gearbox (see Figure 34).

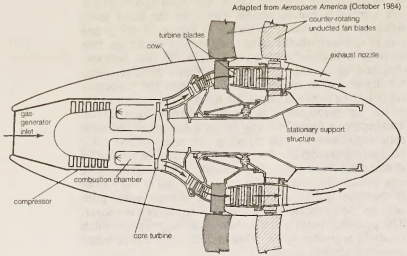

Figure 34: An unducted fan engine (UDF; trademark) with counter-rotating propellers, or unducted fan blades; pusher arrangement.

Medium-bypass turbofans, high-bypass turbofans, and ultrahigh-bypass engines. Moving up in the spectrum of flight speeds to the transonic regime—Mach numbers from 0.75 to 0.9—the most common engine configurations are turbofan engines, such as those in Figures 35A and 35B. In a turbofan, only a part of the gas horsepower generated by the core is extracted to drive a propulsor, which usually consists of a single low-pressure-ratio, shrouded turbocompression stage. The fan is generally placed in front of the core inlet so that the air entering the core first passes through the fan and is partially compressed by it. Most of the air, however, bypasses the core (hence the designation bypass stream) and goes directly to an exhaust nozzle. The core stream, with some modest fraction of the gas horsepower remaining (not extracted to drive the fan) proceeds directly to its own exhaust nozzle.

Bypass ratio

A key parameter for classifying the turbofan is its bypass ratio, defined as the ratio of the mass flow rate of the bypass stream to the mass flow rate entering the core. Since the highest propulsion efficiencies are obtained by the engines with the highest bypass ratios, one would expect to find all engines of that design in this flight speed regime. (Some of the variation derives from historical evolution.) In actuality, however, one finds engines with a broad spectrum of bypass ratios, including medium-bypass engines (with bypass ratios from 2 to 4), high-bypass engines (with bypass ratios from 5 to 8), and ultrahigh-bypass engines, so-called UBEs (with bypass ratios from 9 to 15 or higher). A whole generation of low- and medium-bypass engines has completely supplanted the first generation of aircraft powered by (zero-bypass) turbojet engines. Moreover, that generation was itself supplanted by a third generation of medium- and high-bypass turbofan engines. There are several other reasons why engines with less than the highest bypass ratios hypothetically achievable are still in use. Very high bypass ratios involve the use of fans with very large diameters, which in turn entail very heavy components; this increases the difficulty of installing the engine on aircraft and maintaining sufficient ground clearance. In addition, the weight and complexity of the apparatus required to reverse the direction of the bypass stream (to achieve thrust reversal in order to shorten the aircraft's landing roll) also increases with the bypass ratio. The long-term trend, however, is definitely toward higher and higher bypass ratios.

There are several unique features and ancillary devices found in turbofan engines. As shown in Figure 35A, ultrahigh-bypass engines may have a gearbox between the drive turbine and the fan to simplify the design of the small-diameter turbine (with the attendant high rotative speed) without compromising the performance of the very large-diameter fan (with the attendant low rotative speed). Variable-pitch fan blades are generally required for thrust reversal in such ultrahigh-bypass fans, while in medium- and high-bypass engines the thrust reversing is usually accomplished by introducing blocker doors into the bypass stream. In high- and medium-bypass turbofans such as is shown in Figure 35B, a small but significant improvement in propulsive efficiency can be achieved by mixing the airstream of the hot core and cold bypass streams before the total airstream enters a single jet nozzle.

Provisions for thrust reversing

Low-bypass turbofans and turbojets. In the next higher regime of aircraft flight speed, the low supersonic range from Mach numbers above 1 up to 2 or 3, one finds the application of the simple turbojet (with no bypass stream) and the low-bypass turbofan engine (with a bypass ratio up to 2), such as that pictured in Figure 36.

Although the low-bypass turbofan has the same general appearance as a turbofan with a larger bypass ratio, certain special features are unique to low-bypass engines. The lower total flow in the fan generally involves a higher fan pressure ratio (for equivalent amounts of energy available from the drive turbine), and so such a fan usually has more than one (*i.e.*, two or three) turbocompressor stages. Engines designed to operate at the low supersonic range generally have insufficient thrust in other flight regimes or modes where they must operate for short durations, as, for instance, acceleration through transonic speed, takeoff from high-altitude airports under conditions of extremely high temperatures and high gross weight, or combat maneuvers at high supersonic flight speed. Rather than installing a larger engine to meet these requirements, it is more effective to add an afterburner to a turbofan engine as a means of thrust augmentation (see Figure 36). The

Use of an afterburner

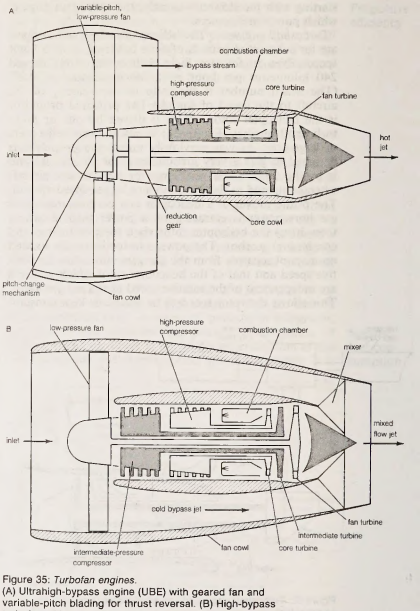

Figure 35: *Turbofan engines.*
(A) Ultrahigh-bypass engine (UBE) with geared fan and variable-pitch blading for thrust reversal. (B) High-bypass turbofan with two-spool core and mixed-flow jet.

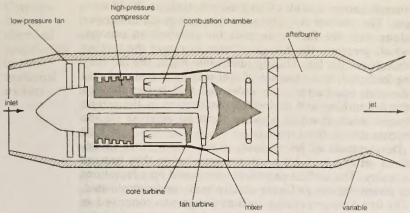

Figure 36: Low-bypass turbofan with afterburner.

afterburner is a secondary combustion system that operates in the exhaust stream of the engine before the stream is introduced into the exhaust nozzle. Such a device is not as fuel-efficient as the main turbofan section of the engine because heat addition occurs at a lower pressure than in the main burner. The afterburner, however, is relatively simple and lightweight, since it does not contain any rotating machinery. For the same reason, it may be operated to a much higher discharge temperature (typically 1,760° C), so that it is capable of augmenting the thrust of the turbofan by as much as 50 percent.

The afterburner in a turbofan usually requires a mixer for mixing the relatively cool bypass air with the hot core stream; the cooler air is otherwise difficult to burn in the low-pressure environment of an afterburner. Also, in both the turbojet and the turbofan with an afterburner, the exhaust nozzle must have a variable throat area to accommodate the large variations in volumetric flow rate between the very hot exhaust stream from the operating afterburner and the cooler airstream discharged from the engine when the afterburner is not in use. Engines intended for supersonic flight generally have a much lower compression-pressure ratio than higher-bypass machines intended for subsonic or transonic operation. A major contributor to this tendency is the additional pressure ratio developed in the engine's inlet as it slows down or diffuses the very high-speed airstream that is ingested as the engine's working fluid—the ram effect. At transonic flight speed this pressure ratio is almost 2:1, so that the engine's compressor may be built to provide that much less pressure where peak pressure is otherwise limiting.

Ram effect

Early generations of jet-propelled aircraft in this low supersonic flight regime were powered by turbojet engines, but subsequent generations built for the same flight regime have largely been equipped with low-bypass turbofans. This substitution of engine type was undertaken primarily because such aircraft expend a great deal of their fuel at subsonic flight speed (*e.g.*, in takeoff, climb, loiter, acceleration, approach, and landing), where the turbofan provides an advantage in propulsive efficiency.

Ramjets and supersonic combustion ramjets. As has been seen, ram pressure plays an increasingly important role in the thermodynamic cycle of power and thrust generation of the jet engine at supersonic flight speeds. For flight speeds above Mach 2.5 or 3, the ram-pressure ratio becomes so high that a turbocompressor is no longer necessary for efficient thrust generation. Indeed, the pressure ratio eventually rises to such high values that the associated high ram temperatures make it difficult or impossible to place high-speed rotating machinery in the flow path without prohibitive amounts of cooling provision. This combination of circumstances gives rise to the ramjet, a jet engine in which the pressure increase is attributable only to the ram effect of the high flight speed; no turbomachinery is involved, and the main thrust producer is an afterburner (see Figure 37).

Absence of a turbine

Ramjets are lightweight and simple power plants, making them ideal candidates for supersonic flight vehicles that are launched from other flight vehicles at extremely high speed. They are less suitable for use in vehicles that must be sufficiently self-powered for subsonic takeoff, climb, and acceleration to supersonic flight speed; the subsonic ram pressure is insufficient to produce any reasonable amount of thrust, and so alternative propulsion devices must be provided.

In the flight regime of Mach 4 or 5, it is usually efficient to decelerate the inlet airstream to subsonic velocity before it enters the combustion system. At still higher Mach numbers, such deceleration becomes more difficult and costly in terms of pressure losses, and it is necessary to make provision for the combustion chamber to burn its fuel in the supersonic airstream. Such specialized ramjets are called scramjets (for supersonic combustion ramjets) and are projected to be fueled by a cryogenically liquified gas (*e.g.*, hydrogen or methane) instead of a liquid hydrocarbon. The primary reason for doing so is to exploit the greater heat release per unit weight of fuels that have a higher ratio of hydrogen to carbon atoms than ordinary fractions of petroleum even though this gain is partly negated by the higher volume per unit of heat release of those same fuels. Another incentive for employing a very cold fuel is that it may be used as a heat sink for cooling a very high-speed (and hence very hot) engine and aircraft structure. The scramjet has an unusual feature: the inlet deceleration and exhaust acceleration occur largely outside the enclosed engine inlet and exhaust ducts against external aircraft surfaces in front of and to the rear of the engine. In effect, the engine itself is little more than a sophisticated supersonic combustion chamber.

Scramjets

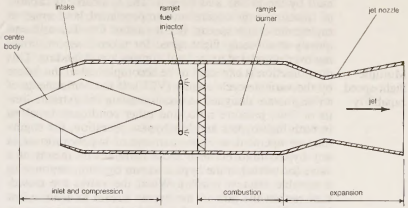

Figure 37: Arrangement of a ramjet.

Hybrid engine types. It is possible to tailor an engine configuration so that the engine is well suited for operation within a given band of the flight spectrum. To have an engine that will perform well in more than one band of the flight spectrum or in more than one regime of operation, it may be necessary to configure the power plant so that it can be converted from one engine type to another by means of variable geometry built into the engine components.

Vertical and short takeoff and landing (V/STOL) propulsion systems. Propulsion systems that provide aircraft with the capability of both vertical and conventional forward flight represent a formidable challenge to the engine designer. V/STOL aircraft have several major categories of engine arrangement. They are as follows:

Vertical and forward flight capability

1. As in a helicopter, the propulsor may consist of a rotor that is driven by one or more turboshaft engines and is installed in such a way as to provide vertical thrust. The entire aircraft must be tilted to give the thrust vector a forward component to achieve forward flight. This arrangement has certain limitations in terms of effectiveness, as borne out by the relative inefficiency of forward flight above a Mach number of 0.2.

2. The propulsors may be mounted on pivots so that they can be rotated from the position in which they give vertical thrust in a takeoff, hover, climb, descent, or landing maneuver and pivoted 90° to provide thrust for conventional forward flight (as in the tilt-rotor aircraft). The prime mover that drives the propulsor may either be tilted with the propulsor or be fixed in the wing and drive the tilting propulsor via a rotating shaft through the pivot axis. In some configurations, the entire wing of the aircraft, carrying fixed engines and propulsors, may be tilted as a single assembly.

3. The engines may be fixed in a position required to produce thrust for forward flight. Their exhaust systems, however, have built-in variable geometry, making it possible to vector the exhaust nozzle (or nozzles) or divert the exhaust gases by means of valves and auxiliary ducts to nozzles mounted in such a way as to provide vertical thrust or lift.

4. The aircraft may include two different sets of engines or propulsors (or both), fixed in position, with one set installed for forward flight and the other for vertical thrust (*i.e.,* the lift engines).

5. The aircraft may use a convertible engine. Such an engine has a single prime mover that is arranged to drive a fan for efficient forward propulsion, to drive a shaft that turns the main helicopter rotor, or to drive both a fan and a shaft. In order to convert from horizontal to vertical flight, variable-pitch fan blades or variable-pitch stators (or both) unload the fan, thereby making mechanical power available to drive the helicopter rotor for vertical movement.

Variable-cycle engines. For aircraft designed to fly mixed missions (*i.e.,* at subsonic, transonic, and supersonic flight speeds) with low levels of fuel consumption, it is desirable to have an engine with the characteristics of both a high-bypass engine (for subsonic flight speed) and a low-bypass engine (for supersonic flight speed). This requirement is typical for such high-speed commercial airliners as the Concorde, a type of supersonic transport built by the British and French. The Concorde is capable of traveling over oceans and unpopulated land areas at supersonic cruise speeds, but it cannot fly efficiently and quietly at subsonic flight speed for takeoff, ascent, cruising over populated areas, and approach and landing. This dual function is expected to be accomplished in the future by the variable-cycle engine (VCE). If the components of an engine are designed to accommodate the extreme limits of flow, pressure ratio, and other conditions involved in both high-bypass and low-bypass operation, the engine may be operated at either extreme of bypass ratio or at any bypass ratio between those extremes by means of a valve (or valves) in the bypass stream (in conjunction with a variable exhaust nozzle). When the valves are closed, they restrict the flow in the bypass stream to achieve low bypass for supersonic flight. When the valves are open, the bypass is increased to its maximum value for efficient subsonic flight.

Multiple flight-speed capability

Turboramjets. As noted above, the ramjet provides a simple and efficient means of propulsion for aircraft at relatively high supersonic flight speeds. It is, however, quite inefficient at transonic flight speeds and is completely ineffective at subsonic velocities. The turboramjet, shown in Figure 38, has been developed to overcome this inadequacy. In this system, a turbofan engine is built into the inlet of a ramjet engine to charge the latter with a pressurized stream of air at subsonic flight speed where ram pressure is insufficient for effective ramjet operation. During supersonic flight the fan blades, if they are of variable pitch, may be feathered so that they do not interfere with the flow of ram air to the ramjet. A separate inlet to the core engine that drives the fan may be closed off so as not to expose the turbomachinery to the hostile environment of the high-temperature ram air.

Built-in turbofan engine

Another variation of the turboramjet does without the core inlet and the core compressor altogether. Instead, the aircraft carries a tank of an oxidizer, such as liquid oxygen. The oxidizer is fed into the core combustion chamber along with the fuel to support the combustion process, which generates the hot gas stream to power the turbine that drives the fan. During supersonic flight, the fan may be feathered, and a surplus of fuel may be introduced into the core combustor. The unburned fuel passes through the fan turbine and undergoes combustion in the ramjet burner when it mixes with the fresh air entering via the bypass stream from the fan. (F.F.E.)

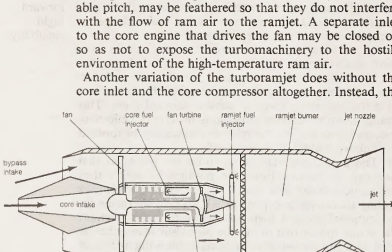

Figure 38: Turboramjet with air-breathing prime mover.

Development of jet engines. Like many other inventions, jet engines were envisaged long before they became a reality. The earliest proposals were based on adaptations of piston engines and were usually heavy and complicated. The first to incorporate a turbine design was conceived as early as 1921, and the essentials of the modern turbojet were contained in a patent in 1930 by Frank Whittle in England. His design was first tested in 1937 and achieved its first flight in May 1941. In Germany, parallel but completely independent work followed issuance of a patent in 1935. It proceeded more rapidly, and the very first flight of a turbojet-powered aircraft, a Heinkel HE-178, came in August 1939. By the end of World War II these prototype aircraft had developed into a few operational turbojet squadrons in the German, British, and U.S. air forces.

In the military area, jet fighter aircraft developed rapidly and were in use during the Korean War (1950–53), flying at speeds of 1,000 kilometres per hour. During the next decade they overcame the sound barrier and established normal operations up to more than twice the speed of sound (Mach 2). Bomber and transport jet aircraft were also able to reach and cruise at supersonic speeds.

Emergence of supersonic jet aircraft

The first civil jet transport, the British de Havilland Comet, flew in 1949, and regular transatlantic jet services were started in 1958 with the Comet 4 and the American Boeing 707. By 1974 more than 90 percent of hours flown throughout the world were flown by jets; the first supersonic airliner, the British-French Concorde, flying at more than twice the speed of sound, entered regular service in January 1976.

During the 1980s various major aircraft manufacturers undertook programs to develop fuel-saving propfan and unducted-fan propulsion systems. Some authorities believe that the next generation of commercial air transport may very well be powered by such advanced-technology propeller engines. (A.D.B./F.F.E.)

ROCKETS

General characteristics and principles of operation. The rocket constitutes a form of jet propulsion (see *Jet engines* above). It differs from the turbojet and other "air-breathing" engines in that all of the exhaust jet consists of the gaseous combustion products of "propellants" carried on board. Like the turbojet engine, the rocket develops thrust by the rearward ejection of mass at very high velocity.

The fundamental physical principle involved in rocket propulsion was formulated by Newton. According to his third law of motion, the rocket experiences an increase in momentum proportional to the momentum carried away in the exhaust,

$$M\Delta v_R = \dot{m}v_e\Delta t = F\Delta t, \qquad (1)$$

where M is the rocket mass, Δv_R is the increase in velocity of the rocket in a short time interval, Δt, $\dot{m}$ is the rate of mass discharge in the exhaust, v_e is the exhaust velocity (relative to the rocket), and F is force. The quantity $\dot{m}v_e$ is the propulsive force, or thrust, produced on the rocket by exhausting the propellant,

$$F = \dot{m}v_e. \qquad (2)$$

Evidently thrust can be made large by using a high mass discharge rate or high exhaust velocity. Employing high $\dot{m}$ uses up the propellant supply quickly (or requires a large supply), and so it is preferable to seek high values of v_e. The value of v_e is limited by practical considerations, determined by how the exhaust is accelerated in the engine and what energy supply is available for the purpose.

Most rockets derive their energy in thermal form by combustion of condensed-phase propellants at elevated

Combustion of chemical propellants in conventional rockets

pressure. The gaseous combustion products are exhausted through a nozzle that converts part of the thermal energy to kinetic energy. The maximum amount of energy available is limited to that provided by combustion or by practical considerations imposed by the high temperature involved. Higher energies are possible if other energy sources (*e.g.*, electric arc or microwave heating) are used in conjunction with the chemical propellants on board the rockets, and extremely high energies are achievable when the exhaust is accelerated by electromagnetic means. As yet, these more exotic systems have not found application because of technical reasons but probably will be used in some future space missions where requisite electrical power sources can be shared by propulsion and other mission requirements (see *Other systems* below).

The exhaust velocity is a figure of merit for rocket propulsion because it is a measure of thrust per unit mass of propellant consumed—*i.e.*,

$$\frac{F}{\dot{m}} = v_e. \tag{3}$$

Values of v_e are in the range 2,000 to 5,000 metres per second for chemical propellants, while values two or three times that are claimed for electrically heated propellants. Values up to 40,000 metres per second are predicted for systems using electromagnetic acceleration. In engineering circles, notably in the United States, the exhaust velocity is widely expressed in units of pound thrust per pound weight per second, which is referred to as specific impulse.

Specific impulse

(In the International System of Units [SI], the unit of specific impulse is newton-seconds per kilogram.) Values in the range 185 to 465 seconds are analogous to the range of exhaust velocities noted above for chemical propellants.

In a typical chemical-rocket mission, anywhere from 50 to 95 percent or more of the takeoff mass is propellant. This can be put in perspective by the equation for burnout velocity (gravity-free flight),

$$v_b = v_e \ln \frac{M_o}{M_s + M_{pay}}$$

$$= v_e \ln \frac{1}{\left(\frac{M_s}{M_p}\right)\left(\frac{M_p}{M_o}\right) + \left(\frac{M_{pay}}{M_o}\right)}. \tag{4}$$

In this expression, M_s/M_p is the ratio of propulsion system and structure weight to propellant weight, with a typical value of 0.09 (the symbol ln represents natural logarithm). M_p/M_o is the ratio of propellant weight to all-up takeoff weight, with a typical value of 0.90. A typical value for v_e for a hydrogen–oxygen system is 3,536 metres per second. From the above equation, the ratio of payload mass to takeoff mass (M_{pay}/M_o) can be calculated. For a low Earth orbit, v_b is about 7,544 metres per second, which would require M_{pay}/M_o to be 0.0374. In other words, it would take a 1,337,000-kilogram takeoff system to put 50,000 kilograms in a low orbit around the Earth. This is an optimistic calculation because equation (4) does not take into account the effect of gravity, drag, or directional corrections during ascent, which would double the takeoff mass. From equation (4) it is evident that there is a direct trade-off between M_s and M_{pay}, so that every effort is made to design for low structural mass, and M_s/M_p is a second figure of merit for the propulsion system. While the various mass ratios chosen depend strongly on the mission, rocket payloads generally represent a small part of the takeoff weight.

Multiple staging

A technique called multiple staging is used in many missions to minimize the size of the takeoff vehicle. A launch vehicle carries a second rocket as its payload, to be fired after burnout of the first stage (which is left behind). In this way, the inert components of the first stage are not carried to final velocity, with the second-stage thrust being more effectively applied to the payload. Most spaceflights use at least two stages. The strategy is extended to more stages in missions calling for very high velocities. The U.S. Apollo manned lunar missions used a total of six stages.

The unique features of rockets that make them useful include the following:

1. Rockets can operate in space as well as in the atmosphere of the Earth.
2. They can be built to deliver very high thrust (a modern heavy space booster has a takeoff thrust approaching 4.5 million kilograms).
3. The propulsion system can be relatively simple.
4. The propulsion system can be kept in a ready-to-fire state (important in military systems).
5. Small rockets can be fired from a variety of launch platforms, ranging from packing crates to shoulder launchers to aircraft (there is no recoil).

These features explain not only why all speed and distance records are set by rocket systems (air, land, space) but also why rockets are the exclusive choice for spaceflight. They also have led to a transformation of warfare, both strategic and tactical. Indeed, the emergence and advancement of modern rocket technology can be traced to weapon developments during and since World War II, with a modest but growing portion being funded through "space agency" initiatives such as the Ariane, Apollo, and Space Shuttle programs.

Chemical rockets. Rockets that employ chemical propellants come in different forms, but all share analogous basic components. These are (1) a combustion chamber where condensed-phase propellants are converted to hot gaseous reaction products, (2) a nozzle to accelerate the gas to high exhaust velocity, (3) propellant containers, (4) a means of feeding the propellants into the combustion chamber, (5) a structure to support and protect the parts, and (6) various guidance and control devices.

Basic parts of a chemical rocket

Chemical rocket propulsion systems are classified into two general types according to whether they burn solid or liquid propellants. Solid systems are usually called motors and liquid systems are referred to as engines. Some developmental work has been carried out on so-called hybrid systems, in which the fuel is a solid and the oxidizer is a liquid, or vice versa. The characteristics of such systems differ greatly depending on the requirements of a given mission.

Solid-rocket motors. The principal features of a solid-rocket motor (SRM) are shown in Figure 39. The propellant consists of one or more pieces mounted directly in the motor "case," which serves both as a propellant tank and combustion chamber. The propellant is usually arranged to protect the motor case from heating. Most modern propellant charges are formed by pouring a viscous mix into the motor case with suitable mold fixtures. The propellant solidifies (usually by polymerization) and the mold fixtures are removed, leaving the propellant bonded to the motor case with a suitably shaped perforation down the middle. During operation the solid burns on the exposed surfaces. These burn away at a predictable rate to give the desired thrust.

The motor case generally consists of a steel or aluminum tube; it has a head-end dome that contains an igniter

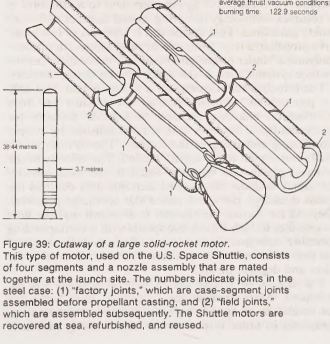

Figure 39: *Cutaway of a large solid-rocket motor.*
This type of motor, used on the U.S. Space Shuttle, consists of four segments and a nozzle assembly that are mated together at the launch site. The numbers indicate joints in the steel case: (1) "factory joints," which are case-segment joints assembled before propellant casting, and (2) "field joints," which are assembled subsequently. The Shuttle motors are recovered at sea, refurbished, and reused.

and an aft-end dome that houses or supports the nozzle. Motor cases ordinarily have insulation on their interior surfaces, especially those not covered by propellant, for protection against thermal degradation. When a mission requires particularly lightweight components, motor cases are often made by filament winding of high-strength fibres on a suitable form. The filaments are held in place by continuous application and curing of plastic during winding. In motor cases, the front and aft domes are wound as integral parts of the case, with suitable openings and fixtures included to permit removal of the (collapsible) motor case form, loading of propellant, and attachment of igniter and nozzle. No matter what type of motor construction is involved, provisions must be made for attaching the structures that connect to the rest of the vehicle and to the launching pad or vehicle. In nearly all applications, the motor case constitutes the main structural component of the rocket and must be designed accordingly.

Propellants for solid-rocket motors are made from a wide variety of substances, selected for low cost, acceptable safety, and high performance. The selection is strongly affected by the specific application. Typical ingredients are

Propellant materials

ammonium perchlorate (a granular oxidizer), powdered aluminum (a fuel), and polybutadiene-acrylonitrile-acrylic acid (a fuel that is liquid during mixing and that polymerizes to a rubbery binder during curing). This combination is used in major U.S. space boosters (*e.g.*, the Space Shuttle and the Titan). Higher performance is achieved by the use of more energetic oxidizers (*e.g.*, cyclotetramethylene tetranitramine [HMX]) and by energetic plasticizers in the binder or by energetic binders such as a nitrocellulose–nitroglycerin system. In military systems, low visibility of the exhaust plume has sometimes been a requirement, which precludes the use of aluminum powder or very much ammonium perchlorate and makes it necessary to use other materials such as HMX and high-energy binder systems that yield combustion products involving mainly carbon, oxygen, hydrogen, and nitrogen.

Propellant charges must meet a variety of often conflicting requirements. From a performance standpoint, they should burn inward at the burning surface in a consistent and predictable manner that is not unduly sensitive to pressure or bulk temperature at a rate typically in the range of 0.2 to 20 centimetres per second. They should be as dense as possible (to maximize the amount of propellant in a given motor size) while still producing reaction products of low molecular weight and high temperature (to maximize exhaust velocity). From a practical standpoint, propellants must be insensitive to accidental ignition stimuli and amenable to safe manufacturing and loading in the motor. Once they have been loaded in the motor, they must achieve and retain the mechanical properties necessary to maintain structural integrity under shipping, storage, and flight conditions. Since the energetic materials used in high-performance propellants are often explosives, manufacturing the propellant to a safe form is a complex technology involving special facilities and strict safety guidelines. To a degree this is true also of less sensitive propellants (*e.g.*, ammonium perchlorate–aluminum–polymeric binder propellants) used in intermediate-performance systems, such as the Space Shuttle booster motors.

Nozzle

The principal requirement for a nozzle is that it be able to produce an optimum flow of the exhaust gas from combustion chamber pressure to exterior pressure (or thereabouts), a function that is accomplished by proper contouring and sizing of the conduit. The contour is initially convergent to a "throat" section. The velocity of the exhaust gas in this region is equal to the local velocity of sound, and the throat cross-sectional area controls the mass discharge rate (and hence the operating pressure). Beyond the throat, the channel is divergent and the flow accelerates to high supersonic speeds with a corresponding pressure decrease. Contours are often carefully designed so that shock waves do not form. (Shock waves slow the flow and degrade thrust.)

The details of nozzle design depend strongly on application. Most applications require at least some use of insulation or special high-temperature materials (*e.g.*, graphite) in order to protect the load-carrying structures from thermal degradation. Many applications require that the direction of the exhaust flow be controllable over a few degrees in order to provide for "steering." This is accomplished in a variety of ways that frequently complicate the design considerably and increase nozzle weight.

The ignition system

The igniter in a solid-rocket motor provides a means of heating the surface of the propellant charge to a high enough temperature to induce combustion. At the same time, the igniter is usually designed to produce some initial pressure increase in the motor to assure more reproducible start-up. The igniter consists of a container of material like a metal–oxidizer mixture that is more easily and quickly ignited than the propellant; it is initiated by an electric squib or other externally energized means. The igniter case is designed to be sealed until fired and to disperse hot and burning products when pressurized by its own burning. In large motors the igniter may feed into a miniature motor containing a fast-burning propellant charge, which exhausts into the main motor to produce ignition and pressurization. Most ignition systems include some kind of "arming" feature that prevents ignition by unintended stimuli.

Thrust levels of solid rockets

The thrust level of a solid rocket is determined by the rate of burning of the propellant charge (mass rate in equation [2]), which is determined by the surface area (S_c) that is burning and the rate (r) at which the surface burns into the solid. The designer chooses a charge geometry that will vary with time during burning in the manner needed for a particular mission and chooses a propellant formulation that gives the desired burning rate. This means that the thrust-time function is not amenable to much intentional modification after manufacture, and most missions using solid-rocket motors are designed to take advantage of the predictability of the thrust-time function rather than to regulate thrust during flight. The lack of real-time control on thrust is compensated for by the ability to achieve extraordinarily high mass-flow rates without the propellant pumps ordinarily used in liquid-propellant rockets. The thrust levels occurring in practice depend on motor operating pressure, which in turn is shown in internal ballistic theory to depend on motor and propellant properties according to the equation

$$p = \left(\rho_p \frac{C}{C_d} \frac{S_c}{A_t}\right)^{1/(1-n)}, \tag{5}$$

where A_t is nozzle throat area, C_d is a nozzle discharge coefficient (that depends on the thermochemical properties of the propellant reaction products), ρ_p is the density of the solid propellant, and C and n are constants in an equation that gives the approximate dependence of burning rate of the propellant on pressure,

$$r = Cp^n. \tag{6}$$

The thrust is then given by an engineering equation,

$$F = C_F A_t p = C_F \left(\rho_p \frac{C S_c}{C_d A_t}\right)^{1/(1-n)} A_t, \tag{7}$$

where C_F depends on nozzle geometry, thermochemical properties, and to a lesser degree on external pressure. Typical values of the quantities in this equation are given in Table 1.

Table 1: Typical Values of Internal Ballistic Variables in Equation (7)

ρ_p	C_d	S_c/A_t	C	n	C_F	coefficient of $A_t(C_F p)$
kg/m³	s/m	—	$N^{-1}m^{1+2n}s^{-1}$	—	—	N/m²
1,762	6.1×10^{-4}	200	4.45×10^{-5}	0.35	1.5	8.21×10^6

In most applications, the need to minimize the mass of motor components is a major design consideration. This need is so important that it is often "bought" at the expense of low safety margins and sometimes by the use of exotic construction and structural materials. These considerations are constantly weighed against the cost of mission failures. With the advent of manned flight and payloads sometimes costing $1 billion or more, the thinking on safety margins and acceptable propulsion-system cost is changing.

Liquid-propellant rocket engines. Liquid-propellant systems carry the propellant in tanks external to the combustion chamber. Most of these engines use a liquid oxidizer and a liquid fuel, which are transferred from their respective tanks by pumps. The pumps raise the pressure well above the operating pressure of the engine, and the propellants are then injected into the engine in a manner that assures atomization and rapid mixing. Liquid-propellant engines have certain features that make them preferable to solid systems in many applications. These features include (1) higher attainable exhaust velocities (v_e), (2) higher mass fractions (propellant mass divided by mass of inert components), and (3) control of operating level in flight (throttleability), sometimes including stop-and-restart capability and emergency shutdown. Also, in some applications it is an advantage that propellant loading is delayed until shortly before launch time, a measure that the use of a liquid propellant allows. These features tend to promote the use of liquid systems in many upper-stage applications where high v_e and high propellant mass fraction are particularly important. Liquid systems also have been used extensively as first-stage launch vehicles for space missions, as, for example, in the Saturn (U.S.), Ariane (European), and Energia (Soviet) launch systems. Many intercontinental ballistic missile (ICBM) systems employ liquid-propellant engines, but solid systems have been widely adopted for these applications in the United States because of their suitability for launch on short notice. The relative merits of solid and liquid propellants in heavy launch vehicles are still under debate and involve not only propulsion performance but also issues related to logistics, capital and operating costs of launch sites, recovery and reuse of flight hardware, and so forth.

Distinctive features

The typical components of a liquid-rocket propulsion system are the engine, fuel tanks, and vehicle structure with which to hold these parts in place and connect to payload and launch pad (or vehicle). The fuel and oxidizer tanks are usually of very lightweight construction, as they operate at low pressure. In some applications, the propellants are cryogenic (*i.e.,* they are substances like oxygen and hydrogen that are gaseous at ambient temperature and must be tanked at very low temperature to be in the liquid state).

Principal components

The liquid-propellant engine itself (Figure 40) consists of a main chamber for mixing and burning the fuel and oxidizer, with the fore end occupied by fuel and oxidizer manifolds and injectors and the aft end comprised of the nozzle. Integral to the main chamber is a coolant jacket through which liquid propellant (usually fuel) is circulated at rates high enough to allow the engine to operate continuously without an excessive increase of temperature in the chamber. Engine operating pressures are usually in the range 1,000 to 10,000 kilopascals (10 to 100 atmospheres). The propellants are supplied to the injector manifold at a somewhat higher pressure, usually by high-capacity turbopumps (one for the fuel and another for the oxidizer). From the outside, a liquid-propellant engine often looks like a maze of plumbing, which connects the tanks to the pumps, carries the coolant flow to and from the cooling jackets, and conveys the pumped fluids to the injector. In addition, engines are generally mounted on gimbals so that they can be rotated a few degrees for thrust direction control, and appropriate actuators are connected between the engine (or engines) and the vehicle structure to constrain and rotate the engine.

Main engines of the Space Shuttle

Each of the main engines of the U.S. Space Shuttle (shown in Figure 40) employs liquid oxygen (LO_2) and liquid hydrogen (LH_2) propellants. These engines represent a very complex, high-performance variety of liquid-propellant rocket. Not only does each have a v_e value of 3,630 metres per second but is also capable of thrust-magnitude control over a significant range (2–1). Moreover, the Shuttle engines are part of the winged orbiter, which is designed to carry both crew and payload for up to 20 missions.

At the opposite extreme of complexity and performance is a hydrazine thrustor used for attitude control of conventional flight vehicles and unmanned spacecraft. Such a system may employ a valved pressure vessel in place of a pump, and the single propellant flows through a catalyst bed that causes exothermic (heat-releasing) decomposition. The resulting gas is exhausted through a nozzle that is suitably oriented for the required attitude correction. Systems of this kind also are used as gas generators for turbopumps on larger rockets.

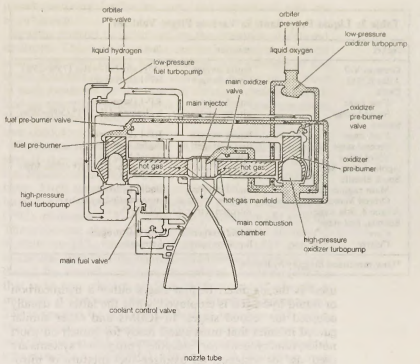

Figure 40: Flow diagram for the Space Shuttle main engine (SSME). Three such engines are mounted on the orbiter.

Most liquid-propellant rockets use bipropellant systems—*i.e.,* those in which an oxidizer and a fuel are tanked separately and mixed in the combustion chamber. Desirable properties for propellant combinations are low molecular weight and high temperature of reaction products (for high exhaust velocity), high density (to minimize tank weight), low hazard factor (*e.g.,* corrosivity and toxicity), and low cost. Choices are based on trade-offs according to the applications. For example, liquid oxygen is widely used because it is a good oxidizer for a number of fuels (giving high flame temperature and low molecular weight) and because it is reasonably dense and relatively inexpensive. It is liquid only below −183° C, which somewhat limits its availability, but it can be loaded into insulated tanks shortly before launch (and replenished or drained in the event of launch delays). Liquid fluorine or ozone are better oxidizers in some respects but involve more hazard and higher cost. The low temperatures of all of these systems require special design of pumps and other components, and the corrosivity, toxicity, and hazardous characteristics of fluorine and ozone have apparently thus far prevented their use in operational systems. Other oxidizers that have seen operational use are nitric acid (HNO_3) and nitrogen tetroxide (N_2O_4), which are liquids under ambient conditions. While they are somewhat noxious chemicals, they are useful in applications where the rocket must be in a near ready-to-fire condition over an extended period of time, as in the case of long-range ballistic missiles.

Predominance of bipropellant systems

Liquid hydrogen is usually the best fuel from the standpoint of high exhaust velocity, and it might be used exclusively were it not for the cryogenic requirement and its low density. Such hydrocarbon fuels as alcohol and kerosene are often preferred because they are liquid under ambient conditions and denser than liquid hydrogen in addition to being more "concentrated" fuels (*i.e.,* they have more fuel atoms in each molecule). The values of exhaust velocity are determined by the relative effects of higher flame (combustion) temperatures and molecular weights of reaction products (as compared to liquid oxygen and liquid hydrogen).

Hydrocarbon fuels

In practice, a variety of choices of propellant systems have been made in major systems, as shown in Table 2. In flights where cryogenic propellants can be utilized (*e.g.,* ground-to-earth-orbit propulsion), liquid oxygen is usually

Table 2: Liquid Propellants in Various Flight Vehicles

rocket	oxidizer	fuel
German V-2	liquid oxygen	ethyl alcohol–water (75%–25%)
Atlas ICBM	liquid oxygen	RP-1 (kerosene)
Delta		
First stage	liquid oxygen	RP-1 (kerosene)
Second stage	nitrogen tetroxide	hydrazine–UDMH* (50%–50%)
Saturn		
First stage	liquid oxygen	RP-1 (kerosene)
Second stage	liquid oxygen	liquid hydrogen
Third stage	liquid oxygen	liquid hydrogen
Apollo Lunar Module	nitrogen tetroxide	hydrazine–UDMH* (50%–50%)
Space Shuttle		
Main engines	liquid oxygen	liquid hydrogen
Orbital Maneuvering System	nitrogen tetroxide	monomethyl hydrazine
Ariane 4, first stage	nitrogen tetroxide	UDMH*
Energia, first stage		
Core	liquid oxygen	liquid hydrogen
Cluster	liquid oxygen	kerosene

*Unsymmetrical dimethylhydrazine.

used as the oxidizer. In first stages either a hydrocarbon or liquid hydrogen is employed, while the latter is usually adopted for second stages. In ICBMs and other similar guided missiles that must stand ready for launch on short notice, noncryogenic (or "storable") propellant systems are used, as, for instance, an oxidizer–fuel mixture of nitrogen tetroxide and hydrazine–unsymmetrical dimethylhydrazine (also designated UDMH; $[CH_3]_2\ NNH_2$). Systems of this sort also find application on longer duration flights such as those involving the Space Shuttle Orbital Maneuvering System and the Apollo Lunar Module. Solid motors have proved useful on long-duration flights, but liquid systems are often preferred because of the need for stop–start capability or thrust control.

Other systems. As suggested earlier, systems using energy sources independent of the propellant fluid have been studied, and they offer promise for some future missions. In certain systems the propellant is heated at elevated pressure by independent means and then accelerated by exhaust through a nozzle. In others the propellant is accelerated by electromagnetic means, in which case at least part of the fluid must be electrically charged first. In these systems the energy source may be nuclear, solar, or beamed energy from an independent source. The outlook for most current missions is that on-board energy sources of this kind would be too heavy, especially for high-thrust missions. There are, however, missions such as manned flights to other planets where sustained low thrust from on-board energy sources would shorten mission duration greatly, saving both time and consumable materials. Such a mission would very likely originate from Earth orbit, with flight system and on-board materials being transported to Earth orbit by chemical rocket propulsion. Electrically heated fluids would probably be used in missions involving manned space stations, where low-thrust capability is needed to control orbit and station attitude. Consideration is even being given to the use of waste products as propellants; these could be heated electrically from power systems already on board for station operational needs.

Possible use of energy sources independent of the propellant fluid

Development of rockets. The technology of rocket propulsion appears to have its origins in the period AD 1200–1300 in Asia, where the first "propellant" (a mixture of saltpetre, sulfur, and charcoal called black powder) had been in use for about 1,000 years for other purposes. As is so often the case with the development of technology, the early uses were primarily military. Powered by black powder charges, rockets served as bombardment weapons, culminating in effectiveness with the Congreve rockets (named for William Congreve, a British officer who was instrumental in their development) of the early 1800s. Performance of these early rockets was poor by modern standards because the only available propellant was black powder, which is not ideal for propulsion. Military use of rockets declined from 1815 to 1936 because of the superior performance of guns.

Use of black powder as a propellant

During the period 1880–1930 the idea of using rockets for space travel grew in public interest. Stimulated by the conceptions of such fiction writers as Jules Verne, the Russian scientist Konstantin E. Tsiolkovsky worked on theoretical problems of propulsion-system design and rocket motion and on the concept of multistage rockets. Perhaps more widely recognized are the contributions of Robert H. Goddard, an American scientist and inventor who from 1908 to 1945 conducted a wide array of rocket experiments. He independently developed ideas similar to those of Tsiolkovsky about spaceflight and propulsion and implemented them, building liquid- and solid-propellant rockets. His developmental work included tests of the world's first liquid-propellant rocket in 1926. Goddard's many contributions to the theory and design of rockets earned him the title of father of modern rocketry. A third pioneer, Hermann Oberth of Germany, developed much of the modern theory for rocket and spaceflight independent of Tsiolkovsky and Goddard. He not only provided inspiration for visionaries of spaceflight but played a pivotal role in advancing the practical application of rocket propulsion that led to the development of rockets in Germany during the 1930s.

The contributions of Tsiolkovsky, Goddard, and Oberth

Due to the work of these early pioneers and a host of rocket experimenters, the potential of rocket propulsion was at least vaguely perceived prior to World War II, but there were many technical barriers to overcome. Development was accelerated during the late 1930s and particularly during the war years. The most notable achievements in rocket propulsion of this era were the German liquid-propellant V-2 rocket and the Me-163 rocket-powered airplane. (Similar developments were under way in other countries but did not see service during the war.) A myriad of solid-propellant rocket weapons also were produced, and tens of millions were fired during combat operations by German, British, and U.S. forces (see WAR, THE TECHNOLOGY OF: *Rockets and missile systems*). The main advances in propulsion that were involved in the wartime technology were the development of pumps, injectors, and cooling systems for liquid-propellant engines and high-energy solid propellants that could be formed into large pieces with reliable burning characteristics.

From 1945 to 1955 propulsion development was still largely determined by military applications. Liquid-propellant engines were refined for use in supersonic research aircraft, intercontinental ballistic missiles (ICBMs), and high-altitude research rockets. Similarly, developments in solid-propellant motors were in the areas of military tactical rocket applications and high-altitude research. Bombardment rockets, aircraft interceptors, antitank weapons, and air-launched rockets for air and surface targets were among the primary tactical applications. Technological advances in propulsion included the perfection of methods for casting solid-propellant charges, development of more energetic solid propellants, introduction of new structural and insulation materials in both liquid and solid systems, manufacturing methods for larger motors and engines, and improvements in peripheral hardware (*e.g.*, pumps, valves, engine-cooling systems, and direction controls). By 1955 most missions called for some form of guidance, and larger rockets generally employed two stages. While the potential for spaceflight was present and contemplated at the time, financial resources were directed primarily toward military applications.

The next decade witnessed the development of large solid-propellant rocket motors for use in ICBMs, a choice motivated by the perceived need to have such systems in ready-to-launch condition for long periods of time. This resulted in a major effort to improve manufacturing capabilities for large motors, lightweight cases, energetic propellants, insulation materials that could survive long operational times, and thrust-direction control. Enhancement of these capabilities led to a growing role for solid-rocket motors in spaceflight. Between 1955 and 1965 the vision of the early pioneers began to be realized with the achievement of Earth-orbiting satellites and manned spaceflight. The early missions were accomplished with liquid-propulsion systems adapted from military rockets. The first successful "all-civilian" system was the Saturn launch vehicle for the Apollo Moon-landing program, which used five 680,000-kilogram-thrust liquid-propellant engines in the first stage. Since then, liquid systems have been employed by most countries for spaceflight applications, though solid boost-

ers have been combined with liquid engines in various first stages of U.S. launch vehicles (those of the Titan 34D, Delta, and Space Shuttle) and solid-rocket motors have been used for several systems for transfer from low Earth orbit to geosynchronous orbit. In such systems, the lower performance of solid-propellant motors is accepted in exchange for the operational simplicity that it provides.

Since 1965, missions have drawn on an ever-expanding technology base, using improved propellants, structural materials, and designs. Present-day missions may involve a combination of several kinds of engines and motors, each chosen according to its function. Because of the performance advantages of energetic propellants and low structural mass, propulsion systems are operated near their safe limits, and one major challenge is to achieve reliability commensurate with the value of the (sometimes human) payload.

(E.W.P.)

Nuclear fission reactors

A nuclear reactor is a device in which a nuclear fission chain reaction takes place under controlled conditions. Such devices are used as research tools, as systems for producing radioisotopes, and most prominently as energy sources. The latter are commonly called power reactors.

Fission is the process in which a heavy nucleus splits into two smaller fragments. A large amount of energy is released in this process, and this energy is the basis of fission power systems. The nuclear fragments are in very excited states and emit neutrons and other forms of radiation. The neutrons can then cause new fissions, which in turn yield more neutrons, and so forth. Such a continuous self-sustaining series of fissions constitutes a fission chain reaction. For a detailed discussion of nuclear fission, see ATOMS: *Fundamentals of the fission process.*

In an atomic bomb the chain reaction is designed to increase in intensity until much of the material has fissioned. This increase is very rapid and produces the extremely sharp, tremendously energetic explosions characteristic of such bombs. In a nuclear reactor the chain reaction is maintained at a controlled, nearly constant level. Nuclear reactors are so designed that they cannot explode like atomic bombs.

Energy release

Most of the energy of fission—about 85 percent of it—is released within a very short time after the process occurs. The rest of the energy comes from the radioactive decay of fission products, which is what the fragments are called after they have emitted neutrons. Radioactive decay continues when the fission chain has been stopped, and its energy must be dealt with in any proper reactor design.

PRINCIPLES OF OPERATION

Chain reaction and criticality. The course of a chain reaction is determined by the probability that a neutron released in fission will cause a subsequent fission. If on the average less than one neutron causes another fission, the rate of fission will decrease with time and ultimately drop to zero. This situation is called subcritical. When an average of one neutron from a fission causes another fission, the fission rate is steady and the reactor is critical. A critical reactor is what is usually desired. When more than one neutron causes a subsequent fission, fission rate and power increase and the situation is termed supercritical. In order to be able to increase power, reactors are designed to be slightly supercritical when all controls are removed.

Reactivity

Reactor control. A parameter called reactivity is positive when a reactor is supercritical, zero at criticality, and negative when the reactor is subcritical. Reactivity can be controlled in various ways: by adding or removing fuel; by changing the fraction of neutrons that leaks from the system; or by changing the amount of an absorber that competes with the fuel for neutrons. Control is generally accomplished by varying absorbers, which are commonly in the form of movable elements—control rods—or sometimes by changing the concentration of the absorber in a reactor coolant. Leakage changes are usually automatic; for example, an increase of power may cause coolant to boil (see below), which in turn increases neutron leakage and reduces reactivity. This, and other types of negative power-reactivity feedbacks, are vital aspects of safe reactor design.

Reactor control is facilitated by the presence of delayed neutrons. These neutrons are emitted by fission products some time after fission has occurred. The fraction of delayed neutrons is small, but there is a sufficient number of such neutrons for the types of changes needed to regulate an operating reactor, and so the chain reaction must "wait" for them before it can respond. This eases operation considerably.

Fissile and fertile materials. All heavy nuclides can fission if they are in an excited enough state, but only a few fission readily when struck by slow (low-energy) neutrons. Such species of atoms are called fissile. The most important of these are uranium-233 (^{233}U), uranium-235 (^{235}U), plutonium-239 (^{239}Pu), and plutonium-241 (^{241}Pu). The only one that occurs in usable amounts in nature is uranium-235, which makes up a mere 0.711 percent of natural uranium by weight. Uranium-233 can be produced by neutron capture in natural thorium (^{232}Th); that is to say, when a nucleus of thorium-232 absorbs a neutron, it becomes uranium-233. Similarly, plutonium-239 is created by neutron capture in uranium-238 (^{238}U; the principal constituent of naturally occurring uranium), and plutonium-241 is formed when a neutron is absorbed into plutonium-240 (^{240}Pu). Plutonium-240 builds up over time in most power reactors. Thorium-232, uranium-238, and plutonium-240 are termed fertile materials because they can be transformed into fissile materials.

A power reactor contains both fissile and fertile materials. The fertile materials replace fissile materials that are destroyed by fission. This permits the reactor to run longer before the amount of fissile material decreases to the point where criticality can no longer be maintained.

Coolant

Heat removal. The energy of fission is quickly converted to heat, the bulk of which is deposited in the fuel. A coolant is therefore required to remove this heat. The most common coolant is water, but any fluid can be used. Heavy water (deuterium oxide), air, carbon dioxide, helium, liquid sodium, sodium-potassium alloy (called NaK), molten salts, and hydrocarbons have all been used in reactors or reactor experiments. Some research reactors are operated at very low power and have no need for a dedicated cooling system; in such units the small amount of heat that is generated is removed by conduction and convection to the environment. Very high power reactors must have extremely sophisticated cooling systems to remove heat quickly and reliably; otherwise, the heat will build up in the reactor fuel and melt it.

Shielding. An operating reactor is a powerful source of radiation, since fission and subsequent radioactive decay produce neutrons and gamma rays, both of which are highly penetrating radiations. A reactor must have special shielding around it to absorb this radiation in order to protect technicians and other reactor personnel. In a popular class of research reactors known as "swimming pools," this shielding is provided by placing the reactor in a large, deep pool of water. In other kinds of reactors, the shield consists of a thick concrete structure around the reactor system. The shield also may contain heavy metals, such as lead or steel, for more effective absorption of gamma rays, and heavy aggregates may be used in the concrete itself for the same purpose.

Critical concentration and size. Not every arrangement of material containing fissile fuel can be brought to criticality. Even if there were no leakage of neutrons from a reactor, a critical concentration of fissile material must be present. Otherwise, absorption of neutrons by other constituents of the reactor will be too high to permit a critical chain reaction to proceed. Similarly, even if there is a high enough concentration for criticality, the reactor must be large enough so that not too many neutrons leak out before being absorbed. This imposes a critical size limit on a reactor of a given concentration.

Although the only useful fissile material in nature, uranium-235, is found in natural uranium, there are just a few combinations and arrangements of this and other materials that can be brought to criticality. To increase the range of feasible reactor designs, enriched uranium can

Use of enriched uranium fuel

be used. Most of today's power reactors employ enriched uranium fuel in which the percentage of uranium-235 has been increased to 3 to 4 percent. This is about five times the concentration in natural uranium. Large plants for enriching uranium exist in several countries; enrichment has now become a commercial enterprise (see below).

Thermal, intermediate, and fast reactors. Reactors are conveniently classified according to the typical energies of the neutrons that cause fission. Neutrons emanating in fission are very energetic; their average energy is around two million electron volts (MeV), 80 million times higher than the energy of atoms in ordinary matter at room temperature. As the neutrons collide with nuclei in a reactor, they lose energy. The choice of reactor materials and of fissile material concentrations determines how much they are slowed down by these collisions before causing fission.

In a thermal reactor, enough collisions are permitted to occur so that most of the neutrons reach thermal equilibrium with the atoms of the reactor at energies of a few hundredths of an electron volt. Neutrons lose energy most efficiently by colliding with light atoms such as hydrogen (mass 1), deuterium (mass 2), beryllium (mass 9), and carbon (mass 12). Materials that contain atoms of this kind—water, heavy water, beryllium metal and oxide, and graphite—are deliberately incorporated into the reactor for this reason and are known as moderators. Since water and heavy water also can function as coolants, they can do double duty in thermal reactors.

Moderators

One disadvantage of thermal reactors is that at low energies uranium-235 and plutonium-239 not only can be fissioned by thermal (or slow) neutrons but also can capture neutrons without undergoing fission. This destroys fissile atoms without any fission to show for it. When neutrons of higher energy cause fission, fewer of these captures occur. To achieve this, a reactor can be built to operate without a moderator. Then, depending on how many collisions take place with heavier atoms before fission occurs, the typical fission-causing neutrons can have energies in the range of 0.5 electron volt to thousands of electron volts (intermediate reactors) or several hundred thousand electron volts (fast reactors). Such reactors require higher concentrations of fissile material to reach criticality than do thermal reactors but are more efficient at converting fertile material to fissile material. Indeed, they can be designed to produce more than one new fissile atom for each fissile atom destroyed. Such reactors are called breeders. Breeder reactors may become particularly important if the world demand for nuclear power turns out to be a long-term one, since their fuel is manufactured from very abundant fertile materials.

Breeder reactors

REACTOR DESIGN AND COMPONENTS

There are a large number of ways in which a reactor may be designed and constructed, and many types have been experimentally realized. Over the years, nuclear engineers have developed reactors with solid fuels and liquid fuels, thick reflectors and no reflectors, forced cooling circuits and natural conduction or convection heat-removal systems, and so on. Most reactors, however, have certain basic components. These are described below.

Core. All reactors have a core, a central region that contains the fuel, fuel cladding, coolant, and, where separate from the latter, moderator. It is in the core that fission occurs and the resulting neutrons migrate.

Fuel elements

The fuel is usually heterogeneous—*i.e.,* it consists of elements containing fissile material along with a diluent. This diluting agent may be fertile material or simply material that has good mechanical and chemical properties and that does not readily absorb neutrons. The diluted fissile material is enclosed in a cladding—a substance that isolates the fuel from the coolant and keeps the radioactive fission products contained.

Fuel types. Different kinds of reactors use different types of fuel elements. For example, the light-water reactor (LWR), which is the most widely used variety for commercial power generation in the United States, employs a fuel consisting of pellets of sintered uranium dioxide loaded into cladding tubes of zirconium alloy that measure about one centimetre in diameter and roughly three to four metres long. These tubes, called pins, are bundled together into a fuel assembly, with the pins arranged in a square lattice. The uranium used in the fuel is 3- to 4-percent enriched. Since light (ordinary) water tends to absorb more neutrons than do other moderators, such enrichment is crucial. The CANDU (Canadian deuterium-uranium) reactor, which is the principal type of heavy-water reactor, uses natural uranium compacted into pellets. These pellets are inserted in tubes arranged in a lattice. Such a fuel assembly measures about one metre in length, and several assemblies are arranged end-to-end within a channel inside the reactor core.

In a high-temperature graphite reactor the fuel is made of small spherical particles containing uranium dioxide at the centre with concentric shells of carbon, silicon carbide, and carbon around them. (These shells serve as microscopic cladding.) The particles are mixed with graphite and encased in a macroscopic graphite cladding. In a sodium-cooled fast reactor, commonly called a liquid-metal reactor (LMR), the fuel consists of dioxide pellets (French design) or uranium-plutonium-zirconium metal alloy pins (U.S. design) in steel cladding.

The most common type of fuel used in research reactors consists of plates of a uranium-aluminum alloy with an aluminum cladding. The uranium is enriched to 20 percent, and silicon, along with aluminum, are included in the "meat" of the plate. A common variety of research reactor, known as TRIGA (from training, research, and isotope-production reactors–General Atomic), employs a fuel of mixed uranium and zirconium hydride in zirconium cladding.

Coolants and moderators. A variety of substances, including light water, heavy water, air, carbon dioxide, helium, liquid sodium, liquid sodium-potassium alloy, and hydrocarbons (oils), have been used as coolants. Such substances are good conductors of heat and serve to carry the thermal energy produced by fission from the core to the steam-generating equipment of the nuclear power plant.

In many cases, the same substance functions as both coolant and moderator, as in the case of light and heavy water. The moderator slows down the fast (high-energy) neutrons emitted in fission to speeds at which they are more likely to induce fission. In doing so, the moderator helps initiate and sustain a fission chain reaction.

Reflector. A reflector is a region of unfueled material surrounding the core. Its function is to scatter neutrons that leak from the core and thereby return some of them to the core. This reduces core size and smooths out the power density. The reflector is particularly important in research reactors, since it is the region in which much of the experimental apparatus is located. Some reflectors are located inside the core as central islands in which high neutron intensities can be achieved for experimental purposes. In most types of power reactors, a reflector is less important, because the reactors are large and do not leak many neutrons. Yet, as it serves to keep the power density uniform, such an unfueled zone of moderator material is left around the core. The liquid-metal reactor represents a special case. Most sodium-cooled reactors are deliberately built to allow a large fraction of their neutrons—those not needed to maintain the chain reaction—to leak from the core. These neutrons are valuable because they can produce new fissile material if they are absorbed by fertile material. Thus, fertile material—generally depleted uranium or its dioxide—is placed around the core to catch the leaking neutrons. Such an absorbing reflector is referred to as a blanket or a breeding blanket.

Reducing the leakage of neutrons

Reactor control elements. All reactors need special elements for control. Although control can be achieved by varying parameters of the coolant circuit or by varying the amount of absorber dissolved in the coolant or moderator, by far the most common method involves the use of special absorbing assemblies—namely, control rods or sometimes blades. Typically a reactor is equipped with three types of rods for different purposes: (1) safety rods for starting up and shutting down the reactor, (2) regulating rods for adjusting the reactor's power rate, and (3) shim rods for compensating for changes in reactivity as fuel is depleted by fission and capture.

Control rods

The most important function of the safety rods is to shut down the reactor, either when such a shutdown is scheduled or in case of a real or suspected emergency. These rods contain enough absorber to terminate a chain reaction under any conceivable condition. They are withdrawn before fuel is loaded and remain available in case a loading error requires their action. After the fuel is loaded, the rods are inserted, to be withdrawn again when the reactor is ready for operation. The mechanism by which they are moved is designed to be fail-safe in the sense that if there is a mechanical failure the safety rods will fall by gravity into the reactor. In some cases, moreover, the safety rods have an automatic feature, such as a fuse, which releases them by virtue of physical effects independent of electronic signals.

Regulating rods are deliberately designed to affect reactivity only by a small degree. It is assumed that at some time the rods might be totally withdrawn by mistake, and the idea is to keep the added reactivity in such cases well within sensible limits. A well-designed regulating rod will add so little reactivity when it is removed that the delayed neutrons will continue to control the rate of power increase.

Shim rods are designed to compensate for the effects of burnup (*i.e.* energy production). Reactivity changes resulting from burnup can be large, but they occur slowly over periods of days to years, as compared to the seconds-to-minutes range over which safety actions and routine regulation take place. Therefore, shim rods may control a significant amount of reactivity, but they will work perfectly well under constraints on their speed of movement. A common way in which shims are operated is by inserting or removing them as regulating rods reach the end of their most useful position range. When this happens, shim rods are moved so that the regulating rods can be reset.

The functions of shim and safety rods are sometimes combined in rods that have low rates of withdrawal but that can be rapidly inserted. This is usually done when the effect of burnup is to decrease reactivity. The rods are only partially inserted at the outset of operation, but the reactor can be quickly shut down by lowering them all the way into the core (scramming). As operation proceeds, the rods are moved farther out so that there is a greater shutdown reactivity margin.

The amount of shim control required can be reduced by the use of a burnable "poison." This is a neutron-absorbing material, such as boron or gadolinium, which will burn off faster than the fissile material does. At the beginning of operation, this controls the extra reactivity that has been built into the fuel to compensate for the amount of fuel consumed. At the end of an operating period, the absorber material will have been almost completely destroyed by neutron capture.

Structural components. These are the parts of a reactor system that hold the reactor together and permit it to function as a useful energy source. The most important structural component is usually the reactor vessel. In both the light-water reactor and the high-temperature gas-controlled reactor (HTGR), a pressure vessel is used so that the coolant can be contained and operated under conditions appropriate for power generation—namely, high temperature and pressure. Within the reactor vessel are structural grids for holding the reactor core and solid reflectors; coolant channels; control-rod guide channels; internal thermohydraulic components (*e.g.*, pumps or steam circulators) in some cases; instrument tubes; and parts of safety systems.

Pressure vessel

Coolant system. The function of a power reactor installation is to extract the heat of nuclear fission and convert it to useful power, generally electricity. The coolant system plays a pivotal role in performing this function. A coolant fluid enters the core at low temperature and leaves it at higher temperature. This higher temperature fluid is then directed to conventional thermodynamic components where the heat is converted into electrical power. In most light-water, heavy-water, and gas-cooled power reactors, the coolant is maintained at high pressure. Sodium and organic coolants operate at atmospheric pressure.

Research reactors have very simple heat removal systems in which coolant is run through the reactor and the heat that is removed is transferred to ambient air or to water without going through a power cycle. In research reactors of the lowest power running at only a few kilowatts, this may involve simple heat exchange to tap water or to a pool of water cooled with ambient air. During operation at higher power levels, the heat is usually removed by means of a small natural-draft cooling tower.

Containment system. Reactors are designed with the expectation that they will operate safely without releasing radioactivity to their surroundings. It is, however, recognized that accidents can occur. An approach using multiple barriers has been adopted to deal with such accidents. These barriers are, successively, the fuel cladding, primary vessel, and thick shielding. As a final barrier, the reactor is housed in a containment structure. This consists basically of the reactor building, which is designed and tested to prevent any radioactivity that escapes from the reactor from being released to the environment. As a consequence, the containment structure must be at least nominally airtight. In practice, it must be able to maintain its integrity under circumstances of a drastic nature, such as accidents in which most of the contents of the reactor core are released to the building. It has to withstand pressure buildups and damage from debris propelled by an explosion within the reactor, and it must pass a test to demonstrate that it will not leak more than a small fraction of its contents over a period of several days, even when its internal pressure is well above that of the surrounding air. The most common form of containment building is a cylindrical structure with a spherical dome, which is characteristic of LWR systems. This is much more typical of nuclear plants than the large cooling tower that is often used as a symbol for nuclear power. (It should be noted that cooling towers are found at large modern coal- and oil-fired power stations as well.)

Relative integrity of containment

Reactors other than those of the LWR type also have containment structures, but they vary in shape and construction. When it can be justified that major pressure buildups are not to be expected, the containment can be any form of airtight structure. In the United States, containment structures are required for all commercial power reactors and all high-power research reactors. In general, low-power research reactors are exempt, based on the common assumption that an accident in such systems will not lead to a widespread release of radioactivity. Reactors operated by the U.S. Department of Energy and by the armed services also are exempt, a matter which has caused considerable controversy. Some of these have containment structures, while others do not.

The concept of containment originated in the United States during the 1950s and has been generally accepted throughout much of the world. The Soviet bloc countries, however, did not concur with this view, and when containment was provided it was generally not up to Western standards. For example, Chernobyl Unit 4, which suffered a catastrophic explosive accident and fire in 1986, merely had an internal structure that could only withstand the loss of function of a single pressure tube. Though called containment, this was a misnomer by Western standards.

The most severe test of a containment system occurred during an accident in the United States in 1979 at Three Mile Island Unit 2, near Harrisburg, Pa. In this installation, a stoppage of core cooling resulted in the destruction, including partial melting, of the entire core and the release of a large part of its radioactivity to the enclosure around the reactor. In spite of a hydrogen deflagration that also occurred during the accident, the containment structure prevented all but a very small amount of radioactivity from entering the environment and must be credited with having prevented a major radioactive release and its consequences.

TYPES OF REACTORS

Most of the world's existing reactors are power reactors. There also are many research reactors, and the navies of many nations include submarines and surface ships driven by propulsion reactors. There are several types of power reactors, but only one, the light-water reactor, is widely

used. Accordingly, this variety is discussed in considerable detail here. Other significant types are briefly described, as are research and propulsion reactors. Some attention is also given to the prospective uses of reactors for space travel and for certain industrial purposes.

Power reactors. *Light-water reactor.* As noted above, LWRs are power reactors that are cooled and moderated with ordinary water. There are two basic types: the pressurized-water reactor (PWR) and the boiling-water reactor (BWR). In the first type, high-pressure, high-temperature water removes heat from the core and is then passed to a steam generator. Here the heat of the coolant is transferred to a stream of water in the generator (the secondary loop in Figure 41B), causing the water to boil and slightly superheat. The steam generated by this serves as the working fluid in a steam-turbine cycle (see *Steam turbines* above).

Pressurized-water reactor and boiling-water reactor

In a boiling-water reactor, water passing through the core is allowed to boil at intermediate pressure, and the steam from the reactor is used directly in the power cycle (see Figure 41A). Although the BWR seems simpler, the PWR has advantages with regard to fuel utilization and power density, and the two concepts have been economically competitive with each other since the 1960s. Both these light-water reactors are fueled with uranium dioxide pellets in zirconium alloy cladding (see above). The BWR fuel is slightly less enriched, but the PWR fuel produces more energy before being discharged, and so these two aspects balance each other out economically. Because the BWR operates at lower pressure, it has a thinner pressure vessel than the PWR; however, because its power density is somewhat lower, the BWR's vessel has a larger diameter for the same reactor power. The internal system of a BWR is more complex, since there are internal recirculation pumps and complex steam separation and drying equipment within its vessel. Though the internals of the PWR are simpler, a BWR power plant is smaller because it has no steam generators. In fact, the steam generators—there are usually four of them in a big PWR plant—are larger than the reactor vessel itself. The control rods of a typical PWR are inserted from the top (through the reactor head), while those of a BWR are inserted from the bottom.

Refueling operation

Light-water reactors are refueled by removing the reactor head—after lowering and unlatching the safety rods in the case of a PWR. This exposes the reactor to visual observation. The pressure vessel is filled to the top with water, and, since the core is near the bottom of the vessel, the water acts as a shield for this operation. Then, the fuel assemblies to be removed are lifted up into a shielded cask within which they are transferred to a storage pool for cooling while they are still highly radioactive. Many of the remaining assemblies are then shifted within the core, and finally fresh fuel is loaded into the empty fuel positions. The purpose of shifting fuel at the time of reload is to achieve an optimal reactivity and power distribution for the next cycle of operation. Reloading is a time-consuming operation. In principle, it could be accomplished in three weeks, but in practice the plant undergoes maintenance during reload, which can take considerably more time—up to a few months. Utilities schedule maintenance and reload during the spring and fall when electricity demand is lowest and the system usually has reserve capacity.

Storage pools for spent fuel

The discharged fuel stored in the storage pool is not only highly radioactive but also continues to produce energy. This energy is removed by natural circulation of the water in the storage pool. Originally it was expected that this spent fuel could be shipped out for reprocessing within two years, but this option is currently practiced only in France. In the United States, storage pools have continued to receive spent fuel, and some of the pools are filling up. Options available to nuclear plant operators are to store the spent fuel more densely than originally planned, to build new pools, or to store the oldest, no longer very hot fuel in above-ground silos (dry storage). Ultimately this fuel will be transferred to the U.S. Department of Energy for reprocessing or waste disposal or both, but this may not happen until the year 2003 or perhaps later if a viable disposal program is not established.

During the 1970s light-water reactors represented the cheapest source of new electricity in most parts of the world, and it still is economical in Japan, Korea, Taiwan, and France and many other European countries. In the United States, however, strict regulation of light-water reactors during the 1980s, coupled with a decrease in reactor research and development activity, have made

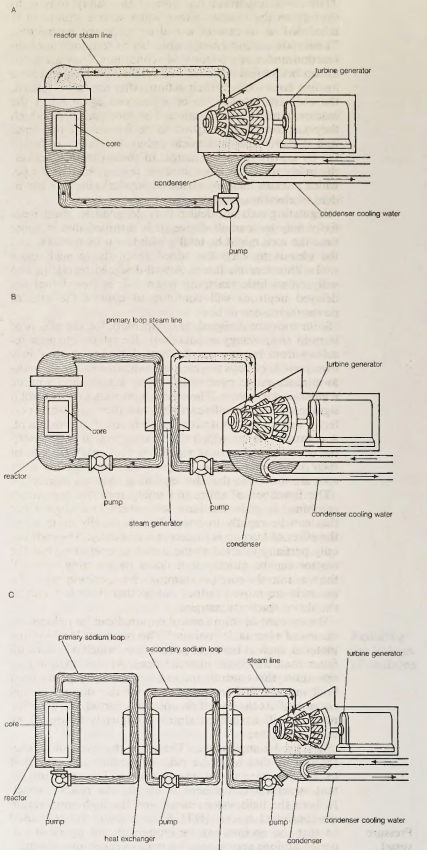

Figure 41: *Basic power cycles in nuclear power plants.* (A) Single-loop cycle; as shown, it represents a boiling-water reactor (BWR), but it could also represent a direct-cycle, high-temperature gas-cooled reactor (HTGR) if the word helium were substituted for the word steam. (B) Two-loop cycle; the primary loop depicted here could constitute a pressurized-water reactor (PWR), a CANDU pressurized heavy-water reactor (PHWR), or a helium HTGR. (C) Three-loop cycle; this is found only in sodium-cooled reactors where an intermediate loop of nonradioactive sodium is provided between the radioactive primary loop and the steam generator.

From the U.S. Department of Energy in R.A. Knief, *Nuclear Energy Technology* (1981), McGraw-Hill, Inc.

the competitive nature of new light-water reactor installations problematic. Plants that have been exceptionally well managed during construction and operation remain competitive; unfortunately, these are not the rule. New designs, developed abroad, may alter this situation, however.

Most recent light-water reactors have had electric capacity ratings of 1,000 megawatts or more. These are not very suitable for the utility industry, which has had only a slow growth in base-load demand since about 1975. Therefore, as of 1989, advanced light-water reactors in the 600-megawatt capacity range were also being considered.

High-temperature gas-cooled reactor. The HTGR, as mentioned above, is fueled with a mixture of graphite and fuel-bearing microspheres. There are two competitive designs of this reactor type: (1) a German system that uses spherical fuel elements of tennis-ball size loaded into a graphite silo and (2) an American version in which the fuel is loaded into precisely located graphite hexagonal prisms. In both variants, the coolant consists of helium pressurized to about 100 bars. In the German system the helium passes through interstices in the bed of the spherical fuel elements, while in the American system it passes through holes in the graphite prisms. Both are capable of operating at very high temperature, since graphite has an extremely high sublimation temperature and helium is completely inert chemically. The hot helium can be used directly as the working fluid in a high-temperature gas turbine, or its heat can be utilized to generate steam for a water cycle. Experimental prototypes of both the American and German designs have been built, but no commercial plants were on order as of the early 1990s.

Sodium-cooled systems

Liquid-metal reactors. Sodium-cooled, fast-neutron-spectrum reactors received much attention during the 1960s and '70s when it appeared that their breeding capabilities would soon be needed to supply fissile material to a rapidly expanding nuclear industry. When it became clear in the 1980s that this was not a realistic expectation, enthusiasm slackened. The developmental work of the previous decades, however, resulted in the construction of a number of liquid-metal reactors around the world—in the United States, the former Soviet Union, France, Britain, Japan, and Germany. Most liquid-metal reactors are fueled with uranium dioxide or mixed uranium–plutonium dioxides. In the United States, however, the greatest success has been with metal fuels. While some liquid-metal reactors are of the loop type, equipped with heat exchangers and pumps outside the primary reactor vessel, others are of the pool variety, featuring a large volume of primary sodium in a pool that also contains the primary pumps and primary-to-secondary heat exchanger. In all types, the heat extracted from the core by primary sodium is transferred to a secondary, nonradioactive sodium loop, which serves as the heat source for a steam generator and turbine. The pool type seems to have some advantage in terms of safety in that the large volume of primary sodium heats up only slowly even if no power is extracted; thus, the reactor is effectively isolated from upsets in the balance of the plant. The reactor core in all such systems is a tightly packed bundle of fuel in steel cladding through which the sodium coolant flows to extract the heat. Most liquid-metal reactors are breeders or are capable of breeding, which is to say that they all produce more fissile material than they consume.

Natural uranium fuel

CANDU reactor. Canada focused its developmental efforts on reactors that would utilize abundant domestic natural uranium as fuel without having to resort to enrichment services that could be supplied only by other countries. The result of this policy was CANDU—the line of natural uranium-fueled reactors moderated and cooled by heavy water. A reactor of this kind consists of a tank, or calandria vessel, containing cold heavy water at normal pressure. The calandria is pierced by pressure tubes made of zirconium alloy, in which the natural uranium fuel is placed and the heavy water coolant is circulated. Power is obtained by transferring the heat from the exiting hot pressurized heavy water to a steam generator and then running the steam from the latter through a conventional turbine cycle. The fuel assembly of a CANDU reactor, which consists of a bundle of short zirconium alloy-clad tubes containing natural uranium dioxide pellets, can be changed while the system is running. A new assembly is simply pushed into one end of a pressure tube and the old one collected as it drops out at the other end. This feature has given the CANDU higher capacity factors than other reactor types. Several countries have purchased CANDU reactors for the same reason that they were developed by Canada—to be independent of imported enrichment services.

Advanced gas-cooled reactor. The advanced gas-cooled reactor (AGR) was developed in Britain as the successor to reactors of the Calder Hall class, which combined plutonium production and power generation. Calder Hall was the first nuclear station to feed an appreciable amount of power into a civilian network. It was fueled with slugs of natural uranium metal canned in aluminum, cooled with carbon dioxide, and employed a moderator consisting of a block of graphite pierced by fuel channels. In the advanced gas-cooled reactor, fuel pins clad in Zircaloy (trademark for alloys of zirconium having low percentages of chromium, nickel, iron, and tin) and loaded with 2-percent enriched uranium dioxide are placed into zirconium-alloy channels that pierce a graphite moderator block. The enriched fuel permits operation to economic levels of fuel burnup. A coolant of carbon dioxide transports heat to a steam generator, activating a steam-turbine cycle. Although a number of advanced gas-cooled reactors have been built in Britain, they have been less trouble-free and more costly than expected, and no new ones are planned.

Other power reactor types. A large variety of reactor types have been built and operated on an experimental basis. A few examples include organic liquid-cooled and -moderated reactors that can operate like a pressurized-water reactor without requiring high pressures in the primary circuit; sodium-cooled, graphite-moderated reactors; and heavy-water reactors built in a pressure-vessel design.

Research reactors. *Water-cooled, plate-fuel reactor.* This is the most common type of research reactor. It uses enriched uranium fuel in plate assemblies (see above) and is cooled with water. Water-cooled, plate-fuel reactors operate over a wide range of thermal power levels, from a few kilowatts to hundreds of megawatts. The systems with the lowest power ratings are usually operated at universities and used primarily for teaching, while those with the highest are used by major research laboratories chiefly for materials testing and research.

Pool-type reactors

A common form of the water-cooled, plate-fuel reactor is the pool reactor, in which the reactor core is positioned at the bottom of a large, deep pool of water. This has the advantage of simplifying both observation and the placement of channels from which beams of neutrons can be extracted. At lower thermal power levels, no pumping is required and the cooling water circulates by natural convection. A heat exchanger is usually located at the top of the pool, where the hottest water is stratified. At higher operating power levels, pumping becomes necessary to augment the natural circulation.

Most pool reactors use the water of the pool as a reflector (see above), but some have blocks of a solid moderator (canned graphite or beryllium metal) around the core that serves as an inner reflector. Graphite and beryllium create a large peak in slow neutron intensity a short distance from the core, which is an advantage when beams of slow neutrons are to be extracted or when such neutrons are used for irradiating materials.

Tank-type reactors

At higher power levels, it becomes more convenient to employ a tank-type reactor because it is simpler to control the flow path of pumped water in such a system. Low-power teaching reactors also are available in the tank form. The core and reflector arrangement in tank-type, plate-fuel research reactors is the same as in the pool-type systems and has the same variations; however, solid concrete shielding is employed around the sides instead of the water shield characteristic of the latter.

TRIGA reactors. The TRIGA system is an increasingly popular variety of research reactor. It is another tank-type, water-cooled system, but its fuel differs from that employed by the above-mentioned research reactors. The fuel

assembly of the TRIGA consists of zirconium-clad rods of mixed uranium and zirconium hydrides. The virtue of this fuel is that it exhibits an extremely large negative power-reactivity coefficient—so large that the reactor can be made strongly supercritical for an instant, causing its power to rise very rapidly, after which it quickly shuts itself down. The resulting power pulse is useful for a number of dynamic experiments. The total energy released in a pulse is not a problem, since the automatic shutdown occurs very quickly and the energy release is proportional to both peak power and pulse duration.

Other research reactors. As in the case of power reactors, a number of different reactor types have seen service as research reactors, and some are still in operation. The variety is so great as to defy cataloging. There have been homogeneous (fueled solution cores), fast, graphite-moderated, heavy-water-moderated, and beryllium-moderated reactors, as well as those adapted to use fuels left over from power reactor experiments. The design of research reactors is much more fluid and sensitive to a greater variety of special research demands than is design for other applications.

Ship propulsion reactors. The original, and still the major, naval application of nuclear energy is the propulsion of submarines. The chief advantage of using nuclear reactors for submarine propulsion is that they, unlike fossil-fuel combustion systems, require no air for power generation. Consequently, a nuclear-powered submarine can remain underwater indefinitely, whereas a conventional diesel-powered submarine must surface periodically to run its engines in air. Nuclear power confers a strategic advantage on naval surface vessels as well because it eliminates their dependence on refueling from vulnerable tankers.

Advantages of nuclear-powered naval craft

The design of U.S. naval nuclear power plants is classified for defense security purposes, and so only general information pertaining to them has been published. It is known that such power plants are fueled with highly enriched uranium and moderated and cooled with light water. The design of the first nuclear submarine power plant, that of the USS *Nautilus,* was heavily influenced by high-power research reactor design. Special features include the incorporation of a very large reactivity margin to accommodate long burnups without refueling and to permit restart after shutdown. For submarine use, the power plant also must be extremely quiet to avoid sonic detection. Various models have been developed to fit the specific requirements of different classes of submarines.

The nuclear power plants for U.S. aircraft carriers are believed to have been derived from the power plant designs for the largest submarines, but again the particulars of their design have not been published.

Besides the United States, Britain, France, Russia, and several other countries have nuclear submarines. In each case, the design was developed in secret, but it is generally believed that they are all rather similar; the demands of the application usually lead to similar solutions. Russia also has a small fleet of nuclear-powered icebreakers, whose power plants are thought to be essentially the same as those in their earliest submarines. As with naval vessels, the ability to operate without refueling is an enormous advantage for Arctic icebreakers.

Nuclear-powered icebreakers

Prototypes of nuclear-powered commercial cargo ships were built and operated by the United States and West Germany but have now been decommissioned. These vessels did not operate very economically, and opposition to their docking in a number of major ports also was a factor in their decommissioning. The prototypes were powered by reactors of the pressurized-water type.

Production reactors. The very first nuclear reactors were built for the express purpose of manufacturing plutonium for nuclear weapons, and the euphemism of calling them production reactors has persisted to this day. At present, most of the material produced by such systems is tritium (^3H, or T), the fuel for hydrogen bombs. Plutonium has a long half-life, and so countries with arsenals of nuclear weapons using plutonium as fissile material generally have more than they expect to need. On the other hand, tritium has a half-life of only about 12 years; thus stocks of this radioactive hydrogen isotope have to be continuously replenished. The United States, for example, operates several reactors moderated and cooled by heavy water that produce tritium at the Savannah River facility in South Carolina.

The plutonium isotope that is most desirable for sophisticated nuclear weapons is plutonium-239. If plutonium-239 is left in a reactor for a long time after production, plutonium-240 builds up as an undesirable contaminant. Accordingly, a major feature of a production reactor is its capability for quick throughput of fuel at a low energy-production level. Any reactor that can be operated this way is a potential production reactor.

The world's first plutonium production reactors, built by the United States at Hanford, Wash., were fueled with natural uranium, moderated by graphite, and cooled by light water. It is believed that the early Soviet production reactors were the same sort, and the French and British versions differed only in that they were cooled with gas. As was noted above, the first significant power reactor, the Calder Hall reactor, was actually a dual-purpose production reactor.

Specialized reactors. Nuclear reactors have been developed to provide electric power and steam heat in far-removed, isolated areas. Russia, for instance, operates smaller power reactors specially designed to supply both electricity and steam for heating to accommodate the needs of a number of remote Arctic communities. Independent developmental work on small automatically operated reactors with similar capabilities has been undertaken by Sweden and Canada.

Reactors have been developed to supply power and propulsion in space. The Soviet Union deployed small intermediate reactors in satellites for powering equipment and telemetry during the 1970s and '80s, but this policy became a target for criticism because at least one reactor-powered spacecraft reentered the atmosphere and deposited radioactive debris in Canada. Developmental activity in the United States has been directed largely toward reactor applications for the Strategic Defense Initiative (SDI) and for such deep-space missions as manned exploration of other planets or the establishment of a permanent lunar base. Reactors for these applications would necessarily be high-temperature systems based on either the HTGR or the LMR design but would use enriched fuel. A power cycle in space must be run at a very high temperature to minimize the size of the radiator from which heat is to be rejected. A reactor for space applications also has to be compact so that it can be shielded with a minimum amount of material.

Nuclear-powered spacecraft

Small pressurized-water reactors have been used in the past to provide power for remote bases in Greenland and Antarctica. Though they have been replaced with oil-fired power plants, it still appears feasible to employ nuclear power for such applications or even for more exotic ones, such as supplying power to permanent undersea camps.

Finally, concepts have been developed, notably in Germany, for employing HTGR systems as sources of high-temperature heat for chemical process industries. An idea that has drawn particular attention involves the use of reactor-generated heat at the mouth of a coal mine to convert the coal into clean gas for delivery by pipeline. Such processes remain economically unattractive at present but may ultimately became feasible as natural sources of fluid fuels are exhausted.

REACTOR SAFETY

Nuclear reactors contain very large amounts of radioactive isotopes—mostly fission products but also such heavy elements as plutonium. If this radioactivity were to escape the reactor, its effects on the people in the vicinity would be severe. The deleterious effects of exposure to high levels of ionizing radiation would include increased rates of cancer and genetic defects, an increased number of developmental abnormalities in children exposed in the womb, and even death within a period of several days to months when irradiation is extreme (see RADIATION: *Major types of radiation injury*). For this reason, a major consideration in reactor design is ensuring that a significant release of radioactivity does not occur. This is ac-

Safeguarding against radioactive contamination of the environment

complished by a combination of preventive measures and mitigating measures. Preventive measures are those that are taken to avoid accidents, and mitigating measures are those that decrease the adverse consequences. Essentially, preventive measures are the set of design and operating rules that are intended to make certain that the reactor is operated safely, while mitigating measures are systems and structures that prevent such accidents as do occur from proceeding to a catastrophic conclusion. Among the most well-known preventive measures are the reports and inspections for double-checking that a plant is properly constructed; rules of operation; and qualification tests for operating personnel to ensure that they know their jobs. The mitigating measures include safety rod systems for quickly shutting down a reactor to prevent a runaway chain reaction; emergency cooling systems for removing the heat of radioactive decay in the event that normal cooling capability is lost; and the containment structure for confining any radioactivity that might escape the primary reactor system. An extreme mitigating measure is the exercising of plans to evacuate personnel who might otherwise be heavily exposed in a reactor installation.

Preventive measures. Since no human activity can be shown to be absolutely safe, all these measures cannot reduce the risks to zero, but it is the aim of the rules and safety systems to minimize the risk to the point where a reasonable individual would conclude they are trivial. What this *de minimis* risk value is, and whether it has been achieved by the nuclear industry, is a subject of bitter controversy, but it is generally accepted that independent regulatory agencies—the United States Nuclear Regulatory Commission (NRC) and similar agencies around the world—are the proper judges of such matters.

To help evaluate the risks from nuclear power plants, the U.S. Atomic Energy Commission (AEC) authorized a major safety study in 1972 (the AEC was disbanded in 1974 and its functions have been assumed by the NRC). The study was conducted with major assistance from a number of laboratories, and it involved the application of probabilistic risk assessment (PRA) techniques for the first time on a system as complex as a large nuclear power reactor. This work resulted in the publication in 1975 of a report titled *Reactor Safety Study*, also known as WASH-1400. The most useful aspect of the study was its delineation of components and accident sequences (scenarios) that were determined to be the most significant contributors to severe accidents.

Probabilistic risk assessment

The *Reactor Safety Study* concluded that the risks of an accident that would injure a large number of people were extremely low for the light-water reactor systems analyzed. This conclusion, however, was subject to very large quantitative uncertainties and was challenged.

One basic problem with probabilistic risk assessment is that it cannot easily be confirmed by experience when the level of risk has been reduced to low values. That is to say, if probabilistic risk assessment predicts that a reactor is subject to, say, one failure in 10,000 years, there is no way to prove that statement with only a few, or even with 10,000, years of experience. Thus, the results of the *Reactor Safety Study* as to risk levels were not confirmable.

There matters stood until 1979, when Three Mile Island Unit 2 suffered a severe accident. Through a combination of operator errors, coupled with the failure of an important valve to operate correctly, cooling water to the core was lost, parts of the core were melted and the rest of it destroyed, and a large quantity of fission products was released from the primary reactor system to the interior of the containment structure. The containment vessel of the reactor building fulfilled its function, and only a small amount of radioactivity was released, demonstrating the wisdom of having this component. Still, a severe accident had occurred.

Many investigations of the Three Mile Island accident followed. Recommendations differed among them, but a common thread was that the human element was a much more important factor in safe operation than had been theretofore recognized. The human element pertained not only to the operating staff but also to the managements of nuclear plants and even to the NRC itself. Following the accident, therefore, many changes in operator training and in technical and inspectorate staffing were implemented, just as a number of hardware enhancements were introduced. It is generally believed that these changes have been effective in reducing the likelihood of the occurrence of accidents as severe as that at Three Mile Island. As a side issue to this, however, the operating costs of nuclear power plants have escalated sharply as more and more highly trained people have been added to the operating staffs.

One area where probabilistic risk assessment has proved useful is with regard to the licensing of new plants, either light-water reactor installations or those of less common reactor types. PRA has the virtue of comparing systems fairly reliably. With better computer hardware and software than were available in 1975, it has become feasible to do PRA analyses of individual plants and compare them. A standard protocol for the NRC in licensing new, and particularly new types of, plants has therefore been that they must demonstrate lower risks than light-water reactors, which have been accepted as the norm.

The significance of the human element, particularly as it relates to plant management and high-level regulatory decision making, was borne out again by the Chernobyl catastrophe of 1986. One of the four reactors in a nuclear power station about 100 kilometres north of Kiev exploded and caught fire as the result of an ill-conceived experiment (a test to see how long the steam turbines would run while coasting to a stop if the reactor would be abruptly shut down). Before the situation had been brought under control, 31 people had died (two from the blast and 29 from radiation exposure), an estimated 25 percent of the radioactive contents of the reactor had been released in a high cloud plume, 135,000 people had to be evacuated, and a large area surrounding the plant received fallout so great that it could not be farmed or pastured. Significant radiation was detected as far north as Scandinavia and as far west as Switzerland. It has been estimated that between 4,000 and 40,000 cases of cancer would ultimately result from this accident (besides the initial several hundred victims), mostly within Ukraine but some in areas far removed from there. Investigation of the accident placed the largest blame, as with the Three Mile Island mishap, on poor management both at the plant and within the government bureaucracy.

The Chernobyl disaster of 1986

Because all such nuclear plant accidents have basically resulted from human failings rather than from some intrinsic factor, most experts believe that nuclear energy can be a safe source of power. A review of the overall performance record shows that there had been, as of 1989, several thousand "reactor-years" of safe power-reactor operation in the Western world, with health effects less damaging than those associated with the extraction of an equal amount of power from coal. Incorporating the lessons learned from past accidents should certainly make future operations safer. There is, however, a condition on the conclusion that nuclear power is by and large a safe form of power. The facilities for generating this power must be designed, built, and operated to high standards by knowledgeable, well-trained professionals; and a regulatory mechanism capable of enforcing these standards must be in place.

Mitigating measures. Two of the principal safety measures, the safety rods and the containment structure, have already been described. Other major safety systems are the emergency core cooling system, which makes it possible to cool the reactor if normal cooling is disrupted, and the emergency power system, which is designed to supply electrical power in case the normal supply is disrupted so that detectors and vital pumps and valves can continue to be operated. An important part of the safety system is the strict adherence to design rules, some of which have been mentioned—namely, the reactor should have a negative power-reactivity coefficient; the safety rods must be injectable under all circumstances; and no single regulating rod should be able to add substantial reactivity rapidly. Another important design rule is that the structural materials used in the reactor must retain acceptable physical properties over their expected service life. Finally, construction is to be covered by stringent quality assurance

rules, and both design and construction must be in accordance with standards set by major engineering societies and accepted by the NRC.

Most probable accidents and risks

According to probabilistic risk assessment studies, three kinds of events are most responsible for the risks associated with light-water reactors—namely, station blackout, transient without scram, and loss of cooling. The nature of each of these mishaps is delineated, as are the proposed countermeasures and the anticipated risks.

In station blackout, a failure in the power line to which the station is connected is postulated. The proposed emergency defense is a secondary electrical system, typically a combination of diesel generators big enough to drive the pumps and a battery supply sufficient to run the instruments. The risk would be that of the emergency generators not accepting load when they are started up. In transient without scram, the event is insertion of reactivity, for example, by an unchecked withdrawal of shim rods. The protective response is the rapid and automatic insertion of the safety rods. The risk would be the safety rods not functioning properly. In loss of cooling, the event is a failure of the normal cooling system to operate, either because of a break in a coolant line or because of an operator error. The emergency response is activation of the emergency core cooling system, and the risk would be that the system fails to operate. The ultimate event in the chain that led to the Three Mile Island accident was loss of emergency cooling by operator action owing to a misinterpretation of what sort of accident was occurring. In all these cases, proper operator action as well as proper functioning of the appropriate backup system are important aspects of emergency response. A final backup capability that is coming into play is the use of computers in an advisory mode to help the operator understand what is happening and suggest proper responses.

Different reactor types pose different types of risk. For example, neither the pool-type liquid-metal reactor nor the high-temperature gas-cooled reactor are at major risk with regard to loss of cooling and perhaps not with regard to station blackout. However, the LMR, and perhaps the HTGR, are at some risk from events that might cause air or water to enter the coolant system. The hazard is that reactor materials, sodium or graphite, could chemically react with air and water. The hazard is greater with sodium in the LMR than it is with graphite in the HTGR.

Another type of risk arises from external events, such as the possibility that earthquakes might initiate one or another major accident. The earthquake risk is minimized by building plants away from faults and by making use of earthquake-resistant mechanical design and construction.

NUCLEAR FUEL CYCLE

No discussion of nuclear power can be complete without a brief exposition of the nuclear fuel cycle. The whole point of a reactor is, after all, to cause fission in nuclear fuel. Moreover, it has turned out that low cost of fueling is the chief reason for the economic competitiveness of nuclear power.

Principal steps of the fuel cycle

The principal steps of the fuel cycle are uranium mining and extraction from its ore (milling), uranium enrichment, fuel fabrication, loading and irradiation in the reactor (fuel management), unloading and cooling, reprocessing, waste packaging, and waste disposal (see Figure 42).

Uranium mining. Uranium is mined from ores whose uranium content is on the order of 0.1 percent (one part per thousand). Most ore deposits are at or near the surface, and whether they are mined by open-pit or deep-mining techniques depends on the depth of the deposit and whether it slopes downward. The ore is crushed and the uranium chemically extracted from it at the mouth of the mine. The residue remains radioactive as it contains long-lived radioactive daughter nuclei of uranium and has to be carefully managed to minimize the release of radioactive contaminants into the environment. The uranium concentrate, which consists of uranium compounds (typically 75 to 95 percent), is shipped to a chemical plant for further purification and chemical conversion.

Enrichment. There are several possible enrichment methods, but the only two that are used on a large scale

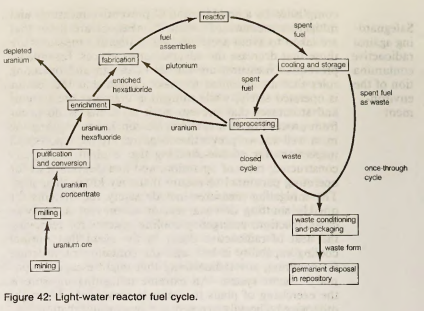

Figure 42: Light-water reactor fuel cycle.

are gaseous diffusion and gas centrifuging. In gaseous diffusion, natural uranium in the form of uranium hexafluoride gas (UF_6), a product of chemical conversion, is allowed to seep through a porous barrier. The molecules of $^{235}UF_6$ penetrate the barrier slightly faster than those of $^{238}UF_6$. Since the percentage of ^{235}U increases by only a very small amount after traversal of the barrier, the process must be repeated over and over in a large number of stages to obtain the desired amount of enrichment.

Gaseous diffusion

In gas centrifuging, the uranium hexafluoride gas is fed into a high-speed centrifuge. The lighter species of this mixture of gaseous molecules including ^{235}U tend to concentrate away from the wall, while the heavier ones accumulate along the wall. The degree of enrichment per stage in a centrifuge is greater than that obtained in a gaseous diffusion chamber, but the centrifuge is a more expensive piece of equipment.

Fabrication. This step involves the conversion of the suitably enriched product material to the chemical form desired for reactor fuel. As of the late 1980s the only fuel fabricated on a large scale was that for light-water reactors.

The chemical form prepared for the light-water reactor is uranium dioxide. Produced in the form of a ceramic powder, this compound is ground into a very fine flour and inserted into a die, where it is pressed into a pellet shape. Next the pellet is sintered in a furnace at 1,500–1,800° C. This sintering, similar to the firing of other ceramic ware, produces a dense ceramic pellet. Such pellets are loaded into prefabricated zirconium alloy cladding tubes, which are then filled with an inert gas and welded shut. These tubes, or pins, are bundled together with proper spacing assured by top and bottom grid plates through which the ends of the pins pass. Together with other necessary hardware, the bundle constitutes a fuel assembly (Figure 43).

Fuel management. Fuel is loaded into a reactor in a careful pattern so as to obtain the most energy production from it before it becomes no longer usable. Fresh fuel is more reactive than old fuel, and this reactivity is used to keep the reactor critical. Typically, a reactor is fueled in cycles, each cycle lasting one to two years, and a fuel batch is kept in the reactor for three or four cycles. At the end of each cycle, the oldest fuel is removed and fresh fuel loaded. The partially burned fuel that remains, however, is shuffled before the fresh fuel is installed. The objective of this procedure is to achieve a loading of maximum reactivity while keeping the power distribution among the different fuel assemblies within technical specifications.

Factors that limit energy production

Fuel burnup—that is, energy production—is limited by two factors. After significant burnup has occurred, the physical properties of the fuel become degraded and it is not prudent to continue to keep it in the reactor. Also, after some burnup, the old fuel no longer contributes useful reactivity to the reactor. The fuel design, including its initial enrichment, is such that these two limits are made to approximately coincide.

Unloading and cooling. Spent reactor fuel is extremely radioactive, and its radioactivity also makes it a source of

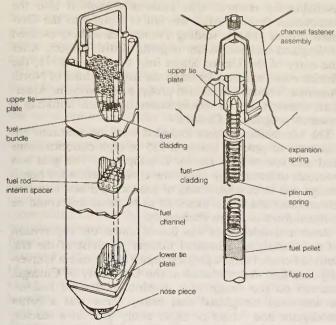

Figure 43: Fuel assembly.
From *General Description of a Boiling Water Reactor*, General Electric Co. (1974)

heat. When the spent fuel is removed from the reactor, it must continue to be both shielded and cooled. This is accomplished by placing the spent fuel in a water storage pool located next to the reactor. The water in the pool contains a large amount of dissolved boric acid, which is a heavy absorber of neutrons; this assures that the fuel assemblies in the pool will not go critical. (Pool water is also a common source of emergency cooling water for the reactor.) Pools vary in size; the older ones are able to accommodate only about 10 years worth of spent fuel. As the pools fill up, more spent fuel storage is needed. As noted earlier, additional storage space can be gained by loading spent fuel into the pool more densely than originally planned, by building a new pool, or by removing the oldest fuel assemblies from the existing pool and storing them in air-cooled concrete and steel silos located above ground. This last method becomes feasible after fuel has been stored for two or three years because radioactivity and heat generation decrease rapidly over this period. Dense storage in existing pools and silo storage both seem to be less expensive than building a new pool.

Reprocessing. Both the converted plutonium and residual uranium-235 in spent fuel can be recycled. Such materials can be recovered by chemically reprocessing the fuel. Equally as significant, reprocessing can reduce the volume and radioactivity of the waste material, which must ultimately be eliminated by some method of permanent disposal. Until 1975 it was generally assumed that after two to five years spent fuel would be delivered to a reprocessing plant. By that time, however, the cost of reprocessing had escalated to a point where its economics became questionable. Also, during the period 1976–81, it was U.S. policy, by presidential directive, not to reprocess. The directive has since been rescinded, but reprocessing is still not done commercially in the United States.

Policy and institutional arrangements are different in France and Britain. Commercial reprocessing plants exist in both countries and are processing spent fuel not only from nuclear plants in the host countries but also from those in others. The reprocessed plutonium can be used not only as fuel for planned future liquid-metal reactors but also to help fuel existing light-water reactors. In the latter application, the plutonium is utilized in mixed oxide form—a combination of uranium and plutonium dioxides having 3 to 6 percent plutonium.

Method-ology

Reprocessing is accomplished by dissolving the spent fuel in nitric acid and contacting the acid solution with oil in which tributyl phosphate (TBP) is dissolved. TBP is a complexing agent for uranium and plutonium, forming compounds with them that bring them into the oil solution. A physical separation of the (immiscible) oil and acid serves to remove the desired products from the nitric acid solution, which still contains all the fission products. The uranium and plutonium can then be washed out of the TBP back into a water solution and separated from each other to the degree desired by means of various techniques. Thus, reprocessing produces three product streams: (1) a purified uranium product, (2) a plutonium product that may be either pure or mixed with uranium, and (3) a waste stream of fission products dissolved in nitric acid.

Waste conditioning. In the absence of reprocessing, the spent fuel is considered to be waste and must be prepared for disposal. This operation is to be performed in a separate facility, for which the Department of Energy has responsibility in the United States. As of 1998, the department is to begin receiving spent fuel from utilities largely on an "oldest-fuel-first" schedule. After brief storage, the fuel pins would be removed from their assemblies. End pieces that contain no fuel would be removed and the pins repacked into a dense lattice emplaced in a corrosion-resistant steel canister. A cover would be welded on and the canister covered with an overpack. This would represent the basic waste form for spent-fuel disposal.

Waste solution from reprocessing

Some waste exists in the form of the fission-product solution that arises from reprocessing. Reprocessed fuel from production reactors also generates this type of waste. The waste solution is completely evaporated, leaving behind the fission products in the solid residue, which is heated until all the constituent nitrate salts are converted to oxides. These oxides are then put into a glass-forming oven and mixed with materials that will produce a borosilicate glass. The fission-product oxides dissolve in the glass as it forms. The glass melt is subsequently poured into a steel canister, 200–400 millimetres in diameter and about one metre high, where it solidifies into a solid glass block. Once covered with an overpack of bentonite clay, the solid canister-like block is ready for disposal.

The glassmaking process for waste conditioning described here is operational on an industrial scale in France and has been tested in many other countries, including the United States.

Geologic disposal method

Waste disposal. *Proposed method.* The waste disposal method currently being planned by all countries with nuclear power plants is called geologic disposal. This means that all conditioned nuclear wastes are to be deposited in mined cavities deep underground. Shafts are to be sunk into a solid rock stratum, with tunnel corridors extending horizontally from the central shaft region and tunnel "rooms" laterally from the corridors. The waste would be emplaced (probably by remotely controlled or robotic devices) in holes drilled into the floors of these rooms, after which the boreholes would be sealed and the rooms and corridors backfilled. When the entire operation is completed (perhaps after about 30 years of operation), the shafts too would be backfilled and sealed.

Risks of nuclear waste disposal. When a holistic view is taken of the nuclear waste disposal process, the risks seem extremely small, yet among the general public these risks are one of the most feared aspects of the nuclear fuel cycle. A great deal of suspicion about the process arises from the numerous incidents of mismanagement of other types of waste, and these fears have been encouraged by antinuclear activists. A number of basic observations on the process of geologic disposal point to the difficulty of resolving differences that are founded on perceptual discrepancies.

Nuclear waste retains its very intense level of radioactivity for several hundred years, but after 1,000 years have passed the remaining radioactivity, while persistent, is at a level comparable to, but greater than, that of a body of natural uranium ore. This separates the safety problem into two time periods: a first millennium during which it is crucial to ensure tight retention of the wastes in the repository, and a subsequent period during which it is only necessary to ensure that any release that occurs is small and slow.

The impingement of groundwater and subsequent corrosion of the waste canisters, followed by dissolution of the waste, provides a possible route for the emergence of the waste in the surface environment. Water migrates slowly in most rock formations. Contrary to the popular belief that any dissolution of the waste and discharge of the

resulting solution to the environment will quickly lead to high-level contamination, only a low level is projected, even in worst-case scenarios.

Migration of radioactive species that has been observed at shallow burial sites for low-level radioactive waste is not an indication that similar migration can be expected in a deep underground repository. In addition to the near insolubility of the waste material, waste form engineering, particularly of corrosion-resistant containers, provides extra protection against such dispersal. Moreover, most of the dispersal problem in shallow disposal sites is caused by biochemical products that do not exist in deep formations; water found at depth is sterile.

Site selection

Finally, a great deal of care is to be expended in selecting the site of the repository. Site selection is probably the biggest problem, both politically and technically. Various conditions are mandatory: the repository must not be near a populated area; the rock stratum selected must be deep (300 metres or more) and, as much as possible, naturally sealed from aquifers; and any discharge of the water table into the surface waters should be slow. Furthermore, the site must be in a tectonically inactive zone so that earthquakes will not break that seal.

The risk of high-level waste burial is almost certainly smaller than the risks of reactor accidents and even than the risks arising from improperly managed mine tailings. Nonetheless, the siting of a repository must be handled with political sensitivity, and the confirmation of acceptable hydrologic and geologic conditions must have a high degree of validity. There are many acceptable sites in principle, but confirming acceptability for any one of them is a large and expensive technical undertaking.

HISTORY OF REACTOR DEVELOPMENT

Soon after the discovery of nuclear fission was announced in 1939, it was also determined that the fissile isotope involved in the reaction was uranium-238 and that neutrons were emitted in the process. Newspaper articles reporting the discovery mentioned the possibility that a fission chain reaction could be exploited as a source of power. World War II, however, began in Europe in September of 1939, and physicists in fission research turned their thoughts to using the chain reaction in a bomb. It was quickly recognized that a high concentration of fissile material would be needed to accomplish this.

Inasmuch as fission had been first discovered in Germany, there was great fear, particularly among refugee physicists from Europe who had fled to America, France, and Britain, that Nazi Germany might develop just such a bomb. As a result, these three countries began working toward the development of atomic bombs, which at that point was still speculation. The most successful program was established in the United States, where President Franklin D. Roosevelt was persuaded by a letter from Albert Einstein to initiate a secret project devoted to this purpose. In early 1940 the U.S. government made funds available for research that eventually evolved into the Manhattan Project. After the fall of France to the German armies (1940), leading French researchers escaped to England and joined the ongoing British project. After the entry of the United States into the war in 1941, the British effort was transferred to the safer confines of North America. Though the British group participated in American research, it was chiefly concerned with initiating a research program in Canada.

The Manhattan Project

The Manhattan Project included work on uranium enrichment to procure uranium-235 in high concentrations and also research on reactor development. The goal was twofold: to learn more about the chain reaction for bomb design and to develop a way of producing a new element, plutonium, which was expected to be fissile and could be isolated from uranium chemically.

Reactor development was placed under the supervision of the leading experimental nuclear physicist of the era, Enrico Fermi. Fermi's project, begun at Columbia University and first demonstrated at the University of Chicago, centred on the design of a graphite-moderated reactor. It was soon recognized that heavy water was a better moderator and would be more easily used in a reactor, and this possibility was assigned to the Canadian research team since heavy-water production facilities already existed in Canada. Fermi's work led the way, and on Dec. 2, 1942, he reported having produced the first self-sustaining chain reaction. His reactor, later called Chicago Pile No. 1 (CP-1), was made of pure graphite in which uranium metal slugs were loaded toward the centre with uranium oxide lumps around the edges. This device had no cooling system, as it was expected to be operated for purely experimental purposes at very low power. CP-1 was subsequently dismantled and reconstructed at a new laboratory site in the suburbs of Chicago, the original headquarters of what is now Argonne National Laboratory. The device saw continued service as a research reactor until it was finally decommissioned in 1953.

Chicago Pile No. 1

On the heels of the successful CP-1 experiment, plans were quickly drafted for the construction of the first production reactors. These were the early Hanford reactors, which were graphite-moderated, natural uranium-fueled, water-cooled devices. As a backup project, a production reactor of air-cooled design was built at Oak Ridge, Tenn.; when the Hanford facilities proved successful, this reactor was completed to serve as the X-10 reactor at what is now Oak Ridge National Laboratory. Shortly after the end of World War II, the Canadian project succeeded in building a zero-power, natural uranium-fueled research reactor, the so-called ZEEP (Zero-Energy Experimental Pile). The first enriched-fuel research reactor was completed at Los Alamos, N.M., at about this time as enriched uranium-235 became available for research purposes (see Table 3). In 1947 a 100-kilowatt reactor with a graphite moderator and uranium metal fuel was constructed in England, and a similar one was built in France the following year.

Table 3: Notable Early Nuclear Reactors

name	location	power output*	distinction	start-up
CP-1 (Chicago Pile No. 1)	Chicago	low	first reactor	1942
ORNL Graphite, or Oak Ridge Graphite Reactor (X = 10)	Oak Ridge, Tenn.	3.8 MW	first megawatt-range reactor	1943
Y-Boiler (LOPO)	Los Alamos, N.M.	low	first enriched-fuel reactor	1944
CP-3 (Chicago Pile No. 3)	Chicago	300 kW	first heavy-water reactor	1944
ZEEP (Zero-Energy Experimental Pile)	Chalk River, Ont.	low	first Canadian reactor	1945
Hanford	Richland, Wash.	>100 MW	first high-power reactor	1945
Clementine	Los Alamos, N.M.	25 kW	first fast-neutron spectrum reactor	1946
NRX	Chalk River, Ont.	42 MW	first high-flux research reactor	1947
GLEEP	Harwell, Eng.	low	first British reactor	1947
ZOE (EL-1)	Châtillon, Fr.	150 kW	first French reactor	1948
LITR (Low-Intensity Test Reactor)	Oak Ridge, Tenn.	3 MW	first plate-fuel reactor	1950
EBR-1 (Experimental Breeder Reactor No. 1)	Idaho Falls, Idaho	1.4 MW	first breeder and first reactor system to produce electricity	1951
JEEP-I	Kjeller, Nor.	350 kW	first international reactor (Norway–Netherlands)	1951
STR (Submarine Thermal Reactor)	Idaho Falls, Idaho		submarine reactor prototype	1953
BORAX-III	Idaho Falls, Idaho	3.5 MW(e)	first U.S. reactor capable of significant electric power generation	1955
Calder Hall A	Calder Hall, Eng.	20 MW(e)	world's first reactor for large-scale commercial power production	1956

*Power output is thermal except where noted as MW(e), signifying electrical.

In 1953 President Dwight D. Eisenhower of the United States announced the Atoms for Peace program. This program established the groundwork for a formal U.S. nuclear power program and expedited international cooperation on nuclear power.

Development of commercial power reactors

The earliest U.S. nuclear power project had been started in 1946 at Oak Ridge, but the program was abandoned in 1948, with most of its personnel being transferred to the naval reactor program that produced the first nuclear-powered submarine, the *Nautilus*. After 1953 the U.S. nuclear power program was devoted to the development of several reactor types, of which three ultimately proved to be successful in the sense that they remain as commercial reactor types or as systems scheduled for future commercial use. These three were the fast breeder reactor (now called LMR); the pressurized-water reactor; and the boiling-water reactor. The first LMR was the Experimental Breeder Reactor, EBR-I, which was designed at Argonne National Laboratory and constructed at what is now the Idaho National Engineering Laboratory near Idaho Falls, Idaho. EBR-I was an early experiment to demonstrate breeding, and in 1951 it produced electricity from nuclear heat for the first time. As part of the U.S. nuclear power program, a much larger experimental breeder, EBR-II was developed and put into service (with power generation) in 1963. The principle of the boiling-water reactor was first demonstrated in a research reactor in Oak Ridge, but development of this reactor type was also assigned to Argonne, which built a series of experimental systems designated BORAX in Idaho. One of these, BORAX-III, became the first U.S. reactor to put power into a utility line on a continuous basis. A true prototype, the Experimental Boiling Water Reactor, was commissioned in 1957. The principle of the pressurized-water reactor had already been demonstrated in naval reactors, and the Bettis Atomic Power Laboratory of the naval reactor program was assigned to build a civilian prototype at Shippingport, Pa. This reactor, the largest of the power-reactor prototypes, is often hailed as the first commercial-scale reactor in the United States.

During the late 1950s and early 1960s a number of true commercial prototype nuclear power plants were built. Of these, the most successful was the light-water reactor system, although the advanced gas-cooled type remained the British standard for many years and the CANDU system prevailed in Canada. From the mid-1960s, larger units were ordered in the expectation of an ever-increasing commercial utilization of nuclear power, and by the early 1970s nuclear plant orders were coming in at such a rapid pace that the unit sizes were increased so as to reduce the number of separate projects that each vendor would have to staff for. By the later years of the decade, however, the surfeit of orders in the United States was followed by a large number of project cancellations. This phenomenon was the result of a sharp decrease over what had been projected as the rate of increase in base-load electricity demand for which the large nuclear plants were designed.

Escalating cost of building new nuclear plants

The new plants were not needed. Moreover, the cost of new nuclear plants had begun to escalate to the point where their economics became questionable. Public fears of nuclear power, stimulated by the Three Mile Island accident, also were a factor.

Similar scenarios have slowed the deployment of nuclear power in several countries besides the United States. On the other hand, France, Japan, South Korea, and Taiwan, which all have few alternative fuel resources, have continued building up their nuclear power capacity. (B.I.S.)

Electric generators and electric motors

A machine that converts mechanical energy into electrical energy is known as an electric generator. One that converts electrical energy into mechanical energy is an electric motor. Actually, the same machine can have energy flow in either direction. The same basic principles apply for both generators and motors. The designation as a generator or motor depends on the intended application.

Major uses

The major use of generators is to produce electrical power for distribution on transmission lines to domestic, commercial, and industrial customers. Generators also produce the electrical power required for automobiles, aircraft, ships, and trains.

Electric motors drive all sorts of mechanical devices. Typical examples are fans and windshield wipers on automobiles, elevators and air conditioners in office buildings, mixers and record players in homes, subway trains in cities, pumps in pipelines, and robots in industry.

Most electric machines rotate, often at high speed. Some, however, produce linear motion such as is required in rapid-transit vehicles.

BASIC PRINCIPLES OF OPERATION

Energy conversion by means of a magnetic field

Most electric machines convert energy by use of a magnetic field that allows force to be transmitted from a stationary to a moving part without physical connection. There are two basic principles exploited in generator and motor operation. The first, originally discovered by the French physicist André-Marie Ampère, states that an electrical conductor carrying a current at right angles to a magnetic field will experience a force at right angles to both the field and the current. The second principle, formulated on the basis of observations made by the English scientist Michael Faraday, states that a potential difference, or voltage, will be established between the ends of an electrical conductor that moves across or perpendicular to a magnetic field. These principles apply for a moving conductor in a stationary magnetic field. They apply equally for a stationary conductor with a moving magnetic field. The various configurations of electric machines consist of means of creating the magnetic field and placing current-carrying conductors in it in such a way as to produce force and voltage.

Elementary generators. These principles are demonstrated in the arrangement shown in Figure 44, where a loop of a conductor is rotated in a magnetic field. This field is created by the use of permanent magnets on each side, directing a horizontal field across a pair of air gaps. A central iron core and an outer iron yoke are used to provide an easy path for the magnetic field to close on itself and thus concentrate the field into the air gaps. Suppose the loop is rotated counterclockwise. In the left-hand section of the loop traveling downward across the field, positive electric charges will be forced toward the observer and negative charges will be forced away. On the right-hand section of the loop, the upward motion across the field forces negative charge toward the observer. The result is the establishment of a potential difference, or voltage, between the two terminals of the loop. This potential difference is proportional to the rate per second at which the magnetic field is being crossed by the two sides of the loop; that is to say, it depends on the density of the field, the length of conductor perpendicular to the field, and the velocity of the conductor perpendicular to the field.

If an electrical load such as a resistor is now connected

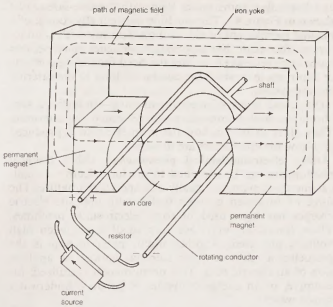

Figure 44: Elementary electric motor.

between the two terminals of the loop, an electric current will flow out of the positive terminal and into the negative terminal. This current will then interact with the magnetic field, resulting in an upward force on the left-hand conductor and a downward force on the right-hand one—*i.e.*, a force perpendicular to both the field and the current direction. To overcome this force and make the loop turn, mechanical torque must be applied to the shaft of the loop. The mechanical power input required will be the product of the force and the conductor velocity (ignoring any losses). Simultaneously, the electric power output to the load will be the product of the potential difference and the current. Ideally, if there were no power losses and no changes in stored energy in this system, the electrical power output would be equal to the mechanical power input. The machine would be acting as an ideal generator, converting mechanical energy into electrical energy.

Elementary motors. Consider now the situation where a source of electric current is attached, possibly through sliding contacts, to the loop terminals in place of the resistor so as to cause current to flow away from the observer in the left-hand side of the loop and toward the observer in the right-hand side. If the loop is rotating counterclockwise with the same velocity as before, the same potential difference will be established between the terminals (again ignoring any losses). Accordingly, there will be electrical power entering the loop equal to the product of the potential difference and the current. The current will interact with the magnetic field to produce a force, downward on the left-hand and upward on the right-hand conductor—*i.e.*, in the direction of the velocity in each case. Thus, there will be a mechanical output power equal to the force–velocity product. Again, ignoring losses and any change in stored energy, the electrical input power will be equal to the mechanical output power. The system will act as an ideal electric motor, converting electrical energy into mechanical energy.

According to the principles of mechanics, for each action there must be an equal and opposite reaction. Thus, in the system shown in Figure 44, the torque on the loop is balanced by an equal and opposite torque on the magnets and the iron yoke. The system can therefore act as a generator or a motor if the loop is held stationary and the magnet system is allowed to rotate.

Rotor and stator

Most, but not all, electric machines are based on the principles just described. A machine of this kind normally contains a rotating part, or rotor, and a stationary part, or stator. In Figure 44, the conductor loop can be fixed to the surface of a rotatable iron core to make up the rotor. In order to reduce the length of the air gaps across which the magnetic field must be produced, the conductor may in fact be imbedded in slots cut into the surface of the iron rotor. The magnetic field may be created by permanent magnets as shown or by electromagnets consisting of current-carrying coils around iron poles. In most machines, the stator is made approximately circular, with both upper and lower flux paths rather than with the one-sided yoke shown in Figure 44. The machine may equally consist of a magnet (permanent or electro-) on the rotor with conductors on the stator. For a permanent-magnet machine, this latter arrangement eliminates the need for sliding contacts or slip rings to connect the conductor loop to the external electric system.

The usual types of electric machine—induction, synchronous, and commutator—have much in common. They differ mainly in how the magnetic field is produced and how the conductors are arranged.

Other electromechanical phenomena. Other physical phenomena can be exploited to produce electromechanical energy converters, usually of a specialized nature. The force of attraction between bodies with opposite electric charges has been used in some electrostatic machines. These forces, however, are very small, even when high voltages are used. Another useful phenomenon is the

Utilization of the piezoelectric effect

piezoelectric effect in which a crystal deforms on application of an electric field. This phenomenon is utilized, for example, in an energy converter to produce underwater sound waves.

Some machines are based on the force of attraction between movable parts of an iron system that carries a magnetic field. These are commonly known as reluctance machines.

The electrical conductors in a machine need not be solid. The conductor can consist of a conducting liquid or gas. Such machines, classified as magnetohydrodynamic devices, can be used to produce electrical power (see *Magnetohydrodynamic power generators* below).

ELECTRIC GENERATORS

Electric generators, as noted above, transform mechanical power into electrical power. The mechanical power is usually obtained from a rotating shaft and is equal to the shaft torque multiplied by the rotational, or angular, velocity. The most significant generators are those used to provide power for transmission and distribution over electric power networks. The mechanical power is obtained from a number of sources: hydraulic turbines at dams or waterfalls; wind turbines; steam turbines using steam produced with heat from the combustion of fossil fuels or from the fission of heavy atomic nuclei; gas turbines burning gas directly in the turbine; or gasoline and diesel engines. The construction and the speed of the generator may vary considerably depending on the characteristics of the mechanical prime mover.

Sources of mechanical power for generators

Nearly all generators used to supply electric power networks generate alternating current, which reverses polarity at a fixed frequency (usually 50 or 60 cycles, or double reversals, per second). Since a number of generators are connected into a power network, they must operate at the same frequency for simultaneous generation. They are therefore known as synchronous generators or, in some contexts, alternators.

Synchronous generators. A major reason for selecting alternating current for power networks is that its continual variation with time allows the use of transformers. These devices convert electrical power at whatever voltage and current it is generated to high voltage and low current for long-distance transmission and then transform it down to a low voltage suitable for each individual consumer (typically 120 or 240 volts for domestic service). The particular form of alternating current used is a sine wave, which has the shape shown in Figure 45. This has been chosen because it is the only repetitive shape for which two waves displaced from each other in time can be added or subtracted and have the same shape occur as the result. The ideal is then to have all voltages and currents of sine shape. The synchronous generator is designed to produce this shape as accurately as is practical. This will become apparent as the major components and characteristics of such a generator are described below.

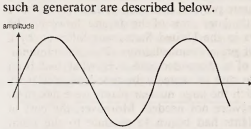

Figure 45: Sine wave.

Rotor. An elementary synchronous generator is shown in cross section in Figure 46. The central shaft of the rotor is coupled to the mechanical prime mover. The magnetic field is produced by conductors, or coils, wound into slots cut in the surface of the cylindrical iron rotor. This set of coils, connected in series, is thus known as the field winding. The position of the field coils is such that the outwardly directed or radial component of the magnetic field produced in the air gap to the stator is approximately sinusoidally distributed around the periphery of the rotor. In Figure 46, the field density in the air gap is maximum outward at the top, maximum inward at the bottom, and zero at the two sides, approximating a sinusoidal distribution.

Field winding

Stator. The stator of the elementary generator in Figure 46 consists of a cylindrical ring made of iron to provide an easy path for the magnetic flux. In this case, the stator contains only one coil, the two sides being accommodated

in slots in the iron and the ends being connected together by curved conductors around the stator periphery. The coil normally consists of a number of turns.

When the rotor is rotated, a voltage is induced in the stator coil. At any instant, the magnitude of the voltage is proportional to the rate at which the magnetic field encircled by the coil is changing with time—*i.e.*, the rate at which the magnetic field is passing the two sides of the coil. The voltage will therefore be maximum in one direction when the rotor has turned 90° from the position shown in Figure 46 and will be maximum in the opposite direction 180° later. The waveform of the voltage will be approximately of the sine form shown in Figure 45.

Frequency. The rotor structure of the generator in Figure 46 has two poles, one for magnetic flux directed outward and a corresponding one for flux directed inward. One complete sine wave is produced for each revolution of the rotor. The frequency of the electrical output, measured in hertz (cycles per second) is therefore equal to the rotor speed in revolutions per second. To provide a supply of electricity at 60 hertz, for example, the prime mover and rotor speed must be 60 revolutions per second, or 3,600 revolutions per minute. This is a convenient speed for many steam and gas turbines. For very large turbines, such a speed may be excessive for reasons of mechanical stress. In this case, the generator rotor is designed with four poles spaced at intervals of 90°. The voltage induced in a stator coil, which spans a similar angle of 90°, will consist of two complete sine waves per revolution. The required rotor speed for a frequency of 60 hertz is then 1,800 revolutions per minute. For lower speeds, a larger number of pole pairs can be used. The possible values of rotor speed, in revolutions per minute, are equal to $120\,f/p$, where f is the frequency and p the number of poles.

Frequency of electrical output and rotor speed

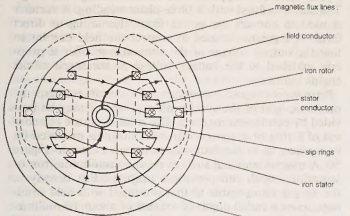

Figure 46: Elementary synchronous machine.

Stator windings. The maximum value of flux density in the air gap is limited by magnetic saturation in the stator and rotor iron, and it is typically about one tesla (weber per square metre). The effective, or root-mean-square (rms), voltage induced in one turn of a stator coil in a 60-hertz generator is about 170 volts for each metre squared of area encompassed by the coil (see below). Large synchronous generators are usually designed for a terminal voltage of several thousand volts. Each stator coil may therefore contain a number of insulated turns of conductor, and each stator winding may consist of a number of similar coils placed in sequential slots in the stator surface and connected in series as shown for the winding a-a' in Figure 47.

Phases. The voltages induced in individual coils in the distributed winding of Figure 47 are somewhat displaced in time from each other. As a result, the maximum winding voltage is somewhat less than the voltage per coil multiplied by the number of coils. The waveform is, however, still of approximately sine form. In the figure the winding a-a' spans two arcs, each of 60°. In order to make use of the whole periphery of the stator surface, two other similar windings are inserted. The voltage induced in winding b-b' will be equal in peak magnitude to that of a-a' but will be delayed in time by one-third of a cycle. The voltage in winding c-c' will be delayed by an additional third of

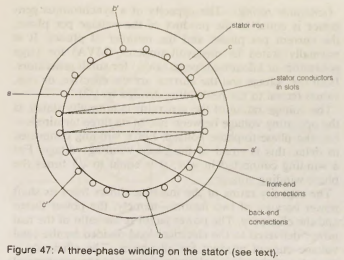

Figure 47: A three-phase winding on the stator (see text).

a cycle. This is known as a three-phase system of windings. The waveforms for the three windings, or phases, are shown in Figure 48.

Three-phase system of windings

The three-phase arrangement has a number of advantages. A single winding, or phase, requires two conductors for transmission of its electrical power to a load. At first glance, it might appear that six conductors would be required for the system in Figure 47. If, however, the waveforms of Figure 48 are considered to be those of the currents flowing in the three-phase windings, it will be seen that the sum of the three currents is zero at every instant in time. Thus, as long as the three phases are loaded equally, the terminals a', b', and c' of Figure 47 can be connected together to form a neutral point that may either be connected to ground or left open. The power of all three phases can be transmitted on three conductors. This connection is called a star, or wye, connection. Alternatively, since the three winding voltages also sum to zero at every instant, the three windings can be connected in series—a' to b, b' to c, and c' to a—to form a delta connection. The output can then be transmitted from only three conductors connected to the three junction points. Other advantages of the three-phase system will become evident in the discussion of electric motors below.

Field excitation. A source of direct current is required for the field winding, as sketched in Figure 46. In very small synchronous generators, this current may be supplied from an external source by fitting the generator shaft with two insulated copper rings, connecting the field coil ends to the rings and providing a connection to the external source through fixed carbon brushes bearing on the rings.

The power required for the field winding is that which is dissipated as heat in the winding resistance. In large generators, this is usually less than 1 percent of the generator rating, but in a generator with a capacity of 1,000 megavolt-amperes this will still be several megawatts. For most large synchronous generators, the field current is provided by another generator, known as an exciter, mounted on the same shaft. This may be a direct-current generator. In most modern installations, a synchronous generator is used as the exciter. For this purpose, the field windings of the exciter are placed on its stator and the phase windings on its rotor. A rectifier mounted on the rotating shaft is used to convert the alternating current to direct current. The field current of the main generator can then be adjusted by controlling the field current of the exciter.

Exciter

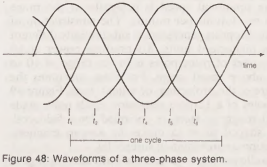

Figure 48: Waveforms of a three-phase system.

Generator rating. The capacity of a synchronous generator is equal to the product of the voltage per phase, the current per phase, and the number of phases. It is normally stated in megavolt-amperes (MVA) for large generators or kilovolt-amperes (kVA) for small generators. Both the voltage and the current are the effective, or rms, values (equal to the peak value divided by $\sqrt{2}$).

Voltage rating

The voltage rating of the generator is normally stated as the operating voltage between two of its three terminals—*i.e.*, the phase-to-phase voltage. For a winding connected in delta, this is equal to the phase-winding voltage. For a winding connected in wye, it is equal to $\sqrt{3}$ times the phase-winding voltage.

The capacity rating of the machine differs from its shaft power because of two factors—namely, the power factor and the efficiency. The power factor is the ratio of the real power delivered to the electrical load divided by the total voltage–current product for all phases. The efficiency is the ratio of the electrical power output to the mechanical power input. The difference between the two power values is the power loss consisting of losses in the magnetic iron due to the changing flux, losses in the resistance of the stator and rotor conductors, and losses from the winding and bearing friction. In large synchronous generators, these losses are generally less than 5 percent of the capacity rating. These losses must be removed from the generator by a cooling system to maintain the temperature within the limit imposed by the insulation of the windings.

High-speed synchronous generators. Generators driven by high-speed turbines are almost always constructed with horizontal shafts. The rotor diameter is usually limited to a maximum of about one metre because of the high centrifugal forces produced. The length of the rotor may be several metres. The rotor shaft and the field structure are made of a solid alloy steel forging in which slots are machined to accept the field coils, as shown in Figure 46. These coils are insulated typically with mica and glass laminate. The coils are held in place by nonmagnetic wedges in the tops of the slots.

The stator provides a path for the continuously varying magnetic flux. The stator core is therefore constructed of thin sheets, or laminations, of magnetic steel. The steel, being an electrical conductor, would tend to short-circuit the voltage induced in it if it were solid. Lamination breaks up the path along the length of the stator and keeps the power losses in the stator steel at an acceptable value. Slots are punched around the inside periphery of the laminations to accommodate the stator coils. In large generators, each stator coil normally contains only one turn.

High-speed generators are enclosed within a closed cylindrical stator housing that extends between the bearings at the two ends. They are cooled by hydrogen gas circulating within the housing and also frequently through ducts within the stator conductors. Very large generators are cooled by circulating water through the stator and rotor conductors.

The ratings of synchronous generators for large power systems extend up to about 2,000 megavolt-amperes. Smaller power systems use generators of lower rating (*e.g.*, 50 megavolt-amperes and up) since it is usually not desirable to have more than 10 percent of the total required system generation in one machine.

Waterwheel generators. Hydraulic turbines are of various types, the choice depending largely on the height of water fall and on the power rating (see *Water turbines* above). The range of speed for which hydraulic turbines give acceptable efficiency is much lower than for steam turbines. The rotational speed is generally in the range of 60 to 720 revolutions per minute. The construction of low-speed synchronous generators is substantially different from that of high-speed units. To produce power at 60 hertz, the number of rotor poles is in the range of 10 to 120 for the above speed range. For these machines the rotor poles are of the projecting, or salient, type. Figure 49 shows two poles of a 12-pole generator. Each pole, made of laminated magnetic steel, is encircled by a field coil. The pole is shaped so as to make the air-gap magnetic field distribution approximately sinusoidal.

Large hydraulic generators may have individual ratings in excess of 200 megavolt-amperes. They are mounted with a vertical shaft directly coupled to the turbine. The combination is usually supported on a single bearing, either above or below. The diameter is made relatively large to obtain a high peripheral velocity at low rotational speeds. The axial length of the generator is relatively short. The windings are frequently water-cooled. The rotor has to be designed to withstand a considerable overspeed condition that may arise if the generator loses its electrical load and there is a significant time delay in cutting off the water flow to the turbine.

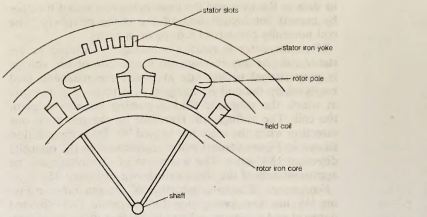

Figure 49: A two-pole cross section of a 12-pole, low-speed synchronous generator.

Generators for motor vehicles. Such vehicles as automobiles, buses, and trucks require a direct-voltage supply for ignition, lights, fans, and so forth. In modern vehicles the electric power is generated by an alternator mechanically coupled to the engine. The alternator normally has a rotor field coil supplied with current through slip rings. The stator is fitted with a three-phase winding. A rectifier is used to convert the power from alternating to direct form. A regulator is used to control the field current so that the output voltage of the alternator-rectifier is properly matched to the battery voltage as the speed of the engine varies.

Alternator-rectifier

Permanent-magnet generators. In small ratings, the magnetic field of the synchronous generator may be provided by permanent magnets. The rotor structure can consist of a ring of magnetic iron with magnets mounted on its surface, as in the four-pole structure shown in Figure 50. A magnet material such as neodymium-boron-iron or samarium-cobalt can provide a magnetic flux density in the air gap comparable to that produced with field windings, using a radial depth of magnet of about 10 millimetres. Other magnet materials such as ferrite can be used, but with a considerable reduction in air-gap flux density and a corresponding increase in generator dimensions.

Permanent-magnet generators are simple in that they require no system for the provision of field current. They are highly reliable. They do not, however, contain any means for controlling the output voltage, and this may vary with changes in load.

Induction generators. An induction machine (see *Induction motors* below) can operate as a generator if it is connected to an electric supply network operating at a substantially constant voltage and frequency. If torque is applied to the induction machine by a prime mover, it will tend to rotate somewhat faster than its synchronous

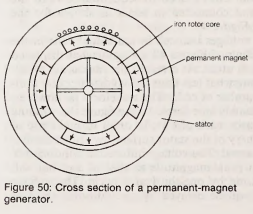

Figure 50: Cross section of a permanent-magnet generator.

speed, which is equal to 120 f/p revolutions per minute, where f is the supply frequency and p is the number of poles in the machine. The rotor conductors, moving faster than the air-gap field, will have induced currents that interact with the field to produce a torque with which to balance that applied by the prime mover. A stator current will then flow into the supply network delivering electrical power. The amount of power delivered is approximately proportional to the difference between the rotor speed and the field speed. This difference is typically of the order of 0.5 to 2 percent of rated speed at rated load.

An induction generator cannot normally provide an independent electrical power source because it does not contain a source of its own magnetic field. Stand-alone induction generators can, however, operate with the aid of appropriate loading capacitors.

Induction generators are frequently preferred over synchronous generators for small and remote hydroelectric sites because they are not subject to loss of synchronism following transient changes in the power system.

Special type of synchronous generator

Inductor alternators. An inductor alternator is a special kind of synchronous generator in which both the field and the output winding are on the stator. In the homopolar type of machine, the magnetic flux is produced by direct current in a field coil concentric with the shaft. In the heteropolar type, the field coils are in slots in the stator.

Voltage is generated in the output windings by pulsations in the flux in individual stator teeth. These pulsations are produced by use of a toothed rotor, which causes the reluctance of the air path from the rotor to each stator tooth to vary periodically with rotation.

Inductor alternators are useful as high-frequency generators. They also are useful in situations requiring high reliability, a feature achieved by their having no electrical connections to the rotor.

Direct-current generators. A direct-current (DC) generator is a rotating machine that supplies an electrical output with unidirectional voltage and current. The basic principles of operation are the same as those for synchronous generators. Voltage is induced in coils by the rate of change of the magnetic field through the coils as the machine rotates. This induced voltage is inherently alternating in form since the coil flux increases and then decreases, usually with a zero average value.

Commutator

The field is produced by direct current in field coils or by permanent magnets on the stator. The output, or armature, windings are placed in slots in the cylindrical iron rotor. A simplified machine with only one rotor coil is shown in Figure 51. The rotor is fitted with a mechanical rotating switch, or commutator, that connects the rotor coil to the stationary output terminals. This commutator reverses the connections at the two instants in each rotation when the rate of change of flux in the coil is zero—*i.e.*, when the enclosed flux is maximum (positive) or minimum (negative). The output voltage is then unidirectional but is pulsating for the single case of one rotor coil. In practical machines, the rotor contains many coils symmetrically arranged in slots around the periphery and all connected in series. Each coil is connected to a segment on a multi-bar commutator. In this way, the output voltage consists of the sum of the induced voltages in a number of individual coils displaced around half the periphery. The magnitude of the output voltage is then approximately constant, containing only a small ripple due to the limited number of coils. The voltage magnitude is proportional to the rotor speed and the magnetic flux. Control of output voltage is normally provided by control of the direct current in the field.

For convenience in design, direct-current generators are usually constructed with four to eight field poles, partly to shorten the end connections on the rotor coils and partly to reduce the amount of magnetic iron needed in the stator. The number of stationary brushes bearing on the rotating commutator is usually equal to the number of poles but may be only two in some designs.

The field current for the generator may be obtained from an external source, such as a battery or a rectifier, as shown in Figure 52A. In this case, the generator is classed as separately excited. Alternatively, it may be noted that

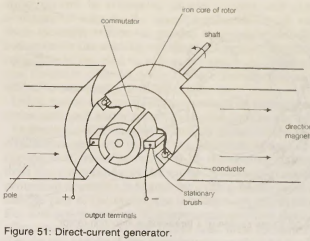

Figure 51: Direct-current generator.

the output of the DC generator is unidirectional and therefore may be used as a source to supply its own field current, as shown in Figure 52B. In this case, the generator is referred to as shunt-excited. It has the advantage of requiring no independent supply. Residual magnetic flux in the iron poles produces a small generated voltage when the machine is brought up to speed. This causes a field current that increases the flux and in turn the generated voltage. The voltage builds up until saturation in the iron limits the voltage produced. The stable value of generated voltage can be adjusted over a limited range by adjusting the value of a resistor placed in series with the field coil across the output terminals.

Shunt-excited DC generator

Direct-current generators were widely used prior to the availability of economical rectifier systems supplied by alternators. For example, they were commonly employed for charging batteries and for electrolytic purposes. In some applications, the direct-current generator retains an advantage over the alternator-rectifier in that it can operate as a motor as well, reversing the direction of power flow. An alternator, by contrast, must be fitted with a more complex rectifier-inverter system to accomplish power reversal.

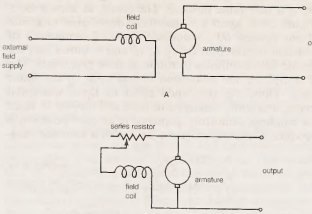

Figure 52: *Types of direct-current generators on the basis of source of field current.*
(A) Separately excited DC generator and (B) shunt-excited DC generator (see text).

ELECTRIC MOTORS

Electric motors transform electrical power into mechanical power. In most instances, the electrical power is obtained from a power distribution network through appropriate control apparatus. In special situations, the electric supply may come from a battery, as, for example, in an automobile.

The basic principles of electric motors were discussed above. Most motors develop their mechanical torque by the interaction of conductors carrying current in a direction at right angles to a magnetic field. The various types of electric motor differ in the ways in which the conductors and the field are arranged and also in the control that can be exercised over mechanical output torque, speed, and position. Each of the major kinds is delineated below.

Differences between motor types

Induction motors. The simplest type of induction motor is shown in cross section in Figure 53. A three-phase

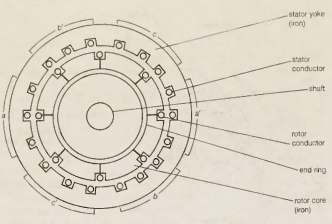

Figure 53: Cross section of a three-phase induction motor.

set of stator windings is inserted in slots in the stator iron. These windings may be connected either in a wye configuration, normally without external connection to the neutral point, or in a delta configuration. The rotor consists of a cylindrical iron core with conductors placed in slots around the surface. In the most usual form, these rotor conductors are connected together at each end of the rotor by a conducting end ring.

The basis of operation of the induction motor may be developed by first assuming that the stator windings are connected to a three-phase electric supply and that a set of three sinusoidal currents of the form shown in Figure 48 flow in the stator windings. Figure 54 shows the effect of the currents in producing a magnetic field across the air gap of the machine. For simplicity, only the central conductor loop for each phase winding is shown. At the instant t_1 in Figure 48, the current in phase a is maximum positive, while that in phases b and c is half that value negative. The result is a magnetic field with an approximately sinusoidal distribution around the air gap with a maximum outward value at the top and a maximum inward value at the bottom. At time t_2 in Figure 48 (*i.e.*, one-sixth of a cycle later), the current in phase c is maximum negative, while that in both phase b and phase a is half value positive. The result, as shown for t_2 in Figure 54 is again a sinusoidally distributed magnetic field but rotated 60° counterclockwise. Examination of the current distribution for t_3, t_4, t_5, and t_6 shows that the magnetic field continues to rotate as time progresses. The field completes one revolution in one cycle of the stator current. Thus, the combined effect of three sinusoidal currents, uniformly displaced in time and flowing in three stator windings uniformly displaced in angular position, is to produce a rotating magnetic field with a constant magnitude and a mechanical angular velocity that depends on the frequency of the electric supply.

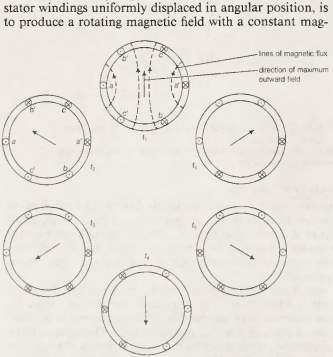

Figure 54: *Production of a rotating magnetic field by three-phase currents in three stator windings.* The symbol ⊙ indicates current flow toward observer; ⊗ denotes current flow away. The t represents the time instants in Figure 48.

The rotational motion of the magnetic field with respect to the rotor conductors causes a voltage to be induced in each, proportional to the magnitude and the velocity of the field relative to the conductors. Since the rotor conductors are short-circuited together at each end, the effect will be to cause currents to flow in these conductors. In the simplest mode of operation, these currents will be about equal to the induced voltage divided by the conductor resistance. The pattern of rotor currents for the instant t_1 of Figure 54 is shown in Figure 55. The currents are seen to be sinusoidally distributed around the rotor periphery and to be located so as to produce a counterclockwise torque on the rotor (*i.e.*, a torque in the same direction as the field rotation). This torque acts to accelerate the rotor and to rotate the mechanical load. As the rotational speed of the rotor increases, its speed relative to that of the rotating field decreases. Thus, the induced voltage is reduced, leading to a proportional reduction in rotor conductor current and in torque. The rotor speed reaches a steady value when the torque produced by the rotor currents equals the torque required at that speed by the load with no excess torque available for accelerating the combined inertia of the load and the motor.

The effect of the rotating field on the rotor

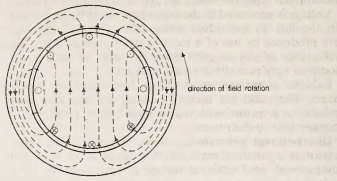

Figure 55: A rotating field and the currents that it produces in shorted rotor conductors.

The mechanical output power must be provided by an electrical input power. The original stator currents shown in Figure 54 are just sufficient to produce the rotating magnetic field. To maintain this rotating field in the presence of the rotor currents of Figure 55, it is necessary that the stator windings carry an additional component of sinusoidal current of such a magnitude and phase as to cancel the effect of the magnetic field that would otherwise be produced by the rotor currents in Figure 55. The total stator current in each phase winding is then the sum of a sinusoidal component to produce the magnetic field and another sinusoid, leading the first by one-quarter of a cycle, or 90°, to provide the required electrical power. The second, or power, component of the current is in phase with the voltage applied to the stator, while the first, or magnetizing, component lags the applied voltage by a quarter cycle, or 90°. At rated load, this magnetizing component is usually in the range of 0.4 to 0.6 of the magnitude of power component.

Power and magnetizing components of current

A majority of three-phase induction motors operate with their stator windings connected directly to a three-phase electric supply of constant voltage and constant frequency. Typical supply voltages range from 230 volts line-to-line for motors of relatively low power (*e.g.*, 0.5 to 50 kilowatts) to about 15 kilovolts line-to-line for high-power motors up to about 10 megawatts.

Except for a small voltage drop in the resistance of the stator winding, the supply voltage is matched by the time rate of change of the magnetic flux in the stator of the machine. Thus, with a constant-frequency, constant-voltage supply, the magnitude of the rotating magnetic field is held constant, and the torque is roughly proportional to the power component of the supply current.

With the induction motor shown in Figures 53, 54, and 55, the magnetic field rotates through one revolution for each cycle of the supply frequency. For a 60-hertz supply, the field speed is then 60 revolutions per second, or 3,600 per minute. The rotor speed is less than the speed of

the field by an amount that is just enough to induce the required voltage in the rotor conductors to produce the rotor current needed for the load torque. At full load, the speed is typically 0.5 to 5 percent lower than the field speed (often called synchronous speed), with the higher percentage applying to smaller motors. This difference in speed is frequently referred to as the slip.

Other synchronous speeds can be obtained with a constant frequency supply by building a machine with a larger number of pairs of magnetic poles, as opposed to the two-pole construction of Figure 53. The possible values of magnetic-field speed in revolutions per minute are $120\ f/p$, where f is the frequency in cycles per second and p is the number of poles (which must be an even number). A given iron frame can be wound for any one of several possible numbers of pole pairs by using coils that span an angle of approximately $(360/p)°$. The torque available from the machine frame will remain unchanged, since it is proportional to the product of the magnetic field and the allowable coil current. Thus, the power rating for the frame, being the product of torque and speed, will be roughly inversely proportional to the number of pole pairs. The most common synchronous speeds for 60-hertz motors are 1,800 and 1,200 revolutions per minute.

Construction of induction motors. The stator frame consists of laminations of silicon steel, usually with a thickness of about 0.5 millimetre. Lamination is necessary since a voltage is induced along the axial length of the steel as well as in the stator conductors. The laminations are insulated from each other by a varnish layer in most cases. This breaks up the conducting path in the steel and limits the losses (known as eddy current losses) in the steel.

The stator coils are normally made of copper; round conductors of many turns per coil are used for small motors, and rectangular bars of fewer turns are employed for larger machines. The coils are electrically insulated. It is common practice to bring only three leads out to a terminal block whether the winding is connected in wye or in delta.

The magnetic part of the rotor is also made of steel laminations, mainly to facilitate stamping conductor slots of the desired shape and size. In most induction motors, the rotor winding is of the squirrel-cage type where solid conductors in the slots are shorted together at each end of the rotor iron by conducting end rings. In such machines there is no need to insulate the conductors from the iron. For motors up to about 300 kilowatts, the squirrel cage often consists of an aluminum casting incorporating the conductors, the end rings, and a cooling fan. For larger motors, the squirrel cage is made of copper, aluminum, or brass bars welded or brazed to end rings of a similar material. In any case, the rotor is very rugged and is also economical to produce in contrast to rotors requiring an electrically insulated winding.

Squirrel-cage rotor winding

The rotor slots need not be rectangular. The shape of the slots can be designed to provide a variety of torque-speed characteristics.

Starting characteristics. When operated from a constant-frequency supply, the three-phase induction motor constitutes essentially a constant-speed drive, with the speed decreasing only 1 to 5 percent as load torque is increased from zero to rated value. In most installations, induction motors can be started and brought up to speed by connecting the stator terminals directly to the electric supply. This establishes the rotating field in the machine. At zero speed the velocity of this field, relative to that of the rotor, is high. If the rotor current were limited only by the resistance of the rotor bars, the rotor currents would be extremely high. The starting current is, however, limited by additional paths for the magnetic field around the stator and rotor conductors, known as flux leakage paths. Usually, the starting current is thus limited to about four to seven times rated current when started on full voltage. The torque at starting is usually in the range of 1.75 to 2.5 times rated value.

If the stator current on starting is larger than is permissible from the electric supply system, the motor may be started on a reduced voltage of about 70 to 80 percent using a step-down transformer. Alternatively, the stator windings can be connected in wye to start and can be switched to delta as the speed approaches rated value. Such measures reduce the starting torque substantially. A reduction in the starting voltage to 75 percent results in a reduction in the electric supply current to 56 percent but also results in only 56 percent of the starting torque that would be provided with full voltage.

Other motor starters insert a resistance or inductance in series with each stator phase during the starting period.

Protection. The heat generated by power losses in the conductors and iron parts of the machine, as well as the friction heat, must be removed by the cooling system to limit the temperature of the motor. The main purpose of protection apparatus is to prevent damage to the most vulnerable part of the motor, the insulation on the windings. For low-power motors, a temperature-sensitive device is often mounted inside the motor and used to switch off the electric supply if the temperature reaches its limiting value. With larger motors, temperature-sensitive detectors may be imbedded at one or more locations in the stator windings.

Wound-rotor induction motors. Some special induction motors are constructed with insulated coils in the rotor similar to those in the stator winding. The rotor windings are usually of a three-phase type with three connections made to insulated conducting rings (known as slip rings) mounted on an internal part of the rotor shaft. Carbon brushes provide for external electric connections.

Use of slip rings

A wound-rotor motor with three resistors connected to its slip rings can provide a high starting torque without excessive starting current. By varying the resistance, a degree of speed control can be provided for some types of mechanical load. The efficiency of such drives is, however, low unless the speed is reasonably close to the synchronous value because of the high losses in the rotor circuit resistances. As an alternative, an electronic rectifier-inverter system can be connected to the rotor slip rings to extract power and feed it back to the electric supply system. This arrangement, normally called a slip recovery system, provides speed control with acceptable efficiency.

Single-phase induction motors. The development of a rotating field in an induction machine requires a set of currents displaced in phase (as shown in Figure 48) flowing in a set of stator windings that are displaced around the stator periphery. While this is straightforward where a three-phase supply is available, most commercial and domestic supplies are only of a single phase, typically with a voltage of 120 or 240 volts. There are several ways in which the necessary revolving field can be produced from this single-phase supply.

Capacitor induction motor. This motor is similar to the three-phase motor except that it has only two windings on its stator displaced 90° from each other. One winding (a-a' in Figure 56) is connected directly to the single-phase supply. For starting, the other winding (commonly called the auxiliary winding) is connected through a capacitor (a device that stores electric charge) to the same supply. The effect of the capacitor is to make the current entering the winding b-b' lead the current in a-a' by approximately 90°, or one-quarter of a cycle, with the rotor at standstill. Thus, the rotating field and the starting torque are provided.

Means of providing a rotating field

As the motor speed approaches its rated value, it is no longer necessary to excite the auxiliary winding to maintain the rotating field. The currents produced in the rotor

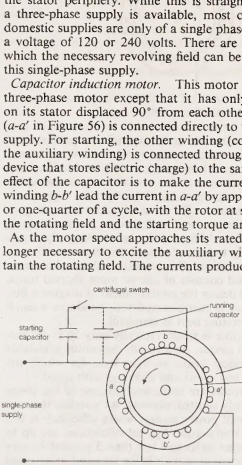

Figure 56: Capacitor induction motor.

squirrel-cage bars as they pass the winding *a-a'* are retained with negligible change as they rotate past the winding *b-b'*. The rotor can continue to generate the rotating field with only winding *a-a'* connected. The winding *b-b'* is usually disconnected by a centrifugal switch that opens when the speed is about 80 percent of rated value.

Power ratings for these capacitor-start induction motors are usually restricted to about two kilowatts for a 120-volt supply and 10 kilowatts for a 230-volt supply because of the limitations on the voltage drop in the supply lines, which would otherwise occur on starting. Typical values of synchronous speed on a 60-hertz supply are 1,800 or 1,200 revolutions per minute for four- and six-pole motors, respectively. Lower-speed motors can be constructed with more poles but are less common.

The efficiency of the motor can be somewhat increased and the line current decreased by the use of two capacitors, only one of which is taken out of the circuit (by means of a centrifugal switch) as the rated speed is approached. The remaining capacitor continues to provide a leading current to phase *b-b'*, approximating a two-phase supply. This arrangement, also shown in Figure 56, is known as a capacitor-start, capacitor-run motor.

Capacitor induction motors are widely used for heavy-duty applications requiring high starting torque. Examples are refrigerator compressors, pumps, and conveyors.

Split-phase motors. An alternative means of providing a rotating field for starting is to use two stator windings, as in Figure 57, where the auxiliary winding *b-b'* is made of more turns of smaller conductors so that its resistance is much larger than that of winding *a-a'*. The effect of this is that the current in phase *b-b'* leads that of *a-a'*, but only by about 20–30 degrees at standstill. While the field is largely pulsating, it contains enough rotating component to provide a starting torque of 1.5 to 2.0 times rated value. To prevent overheating, the auxiliary winding is disconnected by a centrifugal switch when the speed reaches 75–80 percent of rated value.

Use of two stator windings

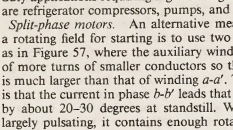

Figure 57: Split-phase induction motor.

These split-phase motors are inexpensive to produce and are installed in many domestic appliances. Where more than one steady speed is required, as in household laundry appliances, the motor may be wound for two alternative pole pairs, one for low speed and the other for high speed.

Shaded-pole motors. The shaded-pole motor is provided with a main winding connected to the single-phase electric supply. In addition, it has a permanently short-circuited winding located ahead of the main winding in the direction of rotation. This second winding is known as a shading coil and consists of one or more shorted turns. The shading coil delays the establishment of magnetic flux in the region that it encircles and thus produces a small component of rotating field at standstill.

The starting torque is small, typically only 30 to 50 percent of the rated torque. As a result, the motor is suitable only for mechanical loads, such as fans, for which the torque is low at low speed and increases with speed.

Shaded-pole motors are inefficient because of the losses in the permanently shorted winding. As a result, they are used only in small power ratings where efficiency is less important than initial cost. Typical efficiencies are up to 30 percent in larger units and less than 5 percent in very small ones. They are used mainly for fans and other small household appliances.

Servomotors. A servomotor is a small induction motor with two stator windings displaced 90° with respect to each other around its periphery. The rotor is usually of the squirrel-cage type but made with relatively high resistance conductors. The purpose of the motor is to provide a controlled torque in either direction of operation. To achieve this, one winding is connected to a single-phase, constant-frequency supply. The other winding is provided with a voltage of the same frequency, displaced 90° in phase. This voltage is normally provided by an electronic amplifier with a low power signal input. The motor torque is approximately proportional to the voltage on this second winding and thus to the signal input. The direction of the torque can be reversed by changing the input signal from 90° leading to 90° lagging.

On some servomotors the rotor consists of an aluminum cup fitted in the air gap between the stator and a stationary iron core. This rotor has low inertia and is capable of high acceleration. Servomotors are made only in small power ratings because of their high losses and low efficiency. They are used in position-control systems.

Linear induction motors. A linear induction motor provides linear force and motion rather than rotational torque. The shape and operation of a linear induction motor can be visualized as depicted in Figure 58 by making a radial cut in a rotating induction machine and flattening it out. The result is a flat "stator," or upper section, of iron laminations that carry a three-phase, multipole winding with conductors perpendicular to the direction of motion. The "rotor," or lower section, could consist of iron laminations and a squirrel-cage winding but more normally consists of a continuous copper or aluminum sheet placed over a solid or laminated iron backing.

An emerging application of linear motors is in rapid-transit vehicles for public transportation. The stator (as described above) is carried on the underside of the vehicle, and the rotor is located between the rails on the track. An advantage of this type of propulsion is that high acceleration and braking can be obtained without dependence on adhesion of the steel wheels to the steel rails in the presence of rain, ice, or a steep slope.

Use of linear motors in rapid-transit vehicles

Electrical power is supplied to such a rapid-transit vehicle through sliding connections to an energized rail or overhead wire. To provide speed control and braking, an electronic power-conditioning apparatus on board the vehicle produces a three-phase output of the desired voltage and frequency.

In an alternative arrangement for vehicle propulsion, the copper and iron sheets of Figure 58 can be placed on the underside of the vehicle and sections of stator can be placed at intervals along the track. This has the advantage that no electric power need be supplied to the vehicle itself.

Linear induction motors also are used to drive conveyors, sliding doors, textile shuttles, and machine tools. Their advantage is that no physical contact is required and thus wear and maintenance are minimized. In another form, linear motors are used as electromagnetic pumps where the rotor consists of a conducting fluid, such as a liquid metal (say, mercury of sodium-potassium alloy).

The efficiency of linear motors is somewhat less than

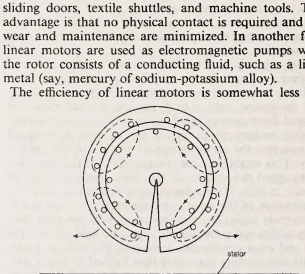

Figure 58: *Evolution of a linear induction motor.* The four-pole induction motor is shown as (top) split open and (bottom) flattened (see text).

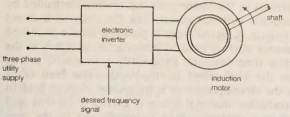

Figure 59: A variable-frequency, variable-speed induction-motor drive system.

that of rotating motors because of end effects. Its "rotor" must be magnetized as it comes under the "stator." This reduces the effectiveness of the first one or two pole spans. The input current is also relatively high because the air gap is usually larger than in rotating machines and more current is required to produce the magnetic field across it.

Induction motors for speed and position control. On a constant-frequency supply, an induction motor is essentially a near-constant speed drive. Induction motors, however, can be used to provide accurate speed and position control in either direction of rotation by furnishing a controllable-voltage, controllable-frequency three-phase supply. This is done by means of an electronic inverter, as shown in Figure 59. Using semiconductor switches (*e.g.*, transistors or thyristors), the utility supply is converted into a set of three near-sinusoidal inputs of controlled voltage and frequency to the stator winding. The speed of the motor will then approach the synchronous value of 120 f/p revolutions per minute for a controlled frequency of f cycles per second. Reversal of the phase sequence from *abc* to *acb* reverses the direction of the torque. For accurate control of speed or of position, the speed of the shaft can be monitored by a tachometer or position sensor and compared with a signal representing the desired value. The difference is then used to control the inverter frequency. Generally, the voltage varies directly with the frequency to keep the magnitude of the magnetic field constant.

Synchronous motors. Such a motor is one in which the rotor normally rotates at the same speed as the revolving field in the machine. The stator is similar to that of an induction machine (as in Figure 53) consisting of a cylindrical iron frame with windings, usually three-phase, located in slots around the inner periphery. The difference is in the rotor, which normally contains an insulated winding connected through slip rings or other means to a source of direct current (see Figure 46).

The principle of operation of a synchronous motor can be understood by considering the stator windings to be connected to a three-phase alternating-current supply. The effect of the stator current is to establish a magnetic field rotating at 120 f/p revolutions per minute for a frequency of f hertz and for p poles. A direct current in a p-pole field winding on the rotor will also produce a magnetic field rotating at rotor speed. These two magnetic fields will tend to align with each other. With no load torque, they may be assumed to be in alignment. As mechanical load is applied, the rotor slips back a number of degrees with respect to the rotating field of the stator, developing torque and continuing to be drawn around by this rotating field. The angle between the fields increases as load torque is increased. The maximum available torque is achieved for given magnitudes of stator and rotor currents when the angle by which the rotor field lags the stator field is 90°. Application of more load torque will stall the motor.

One advantage of the synchronous motor is that the magnetic field of the machine can be produced by the direct current in the field winding, so that the stator windings need to provide only a power component of current in phase with the applied stator voltage—*i.e.*, the motor can operate at unity power factor. This condition minimizes the losses and heating in the stator windings.

The power factor of the stator electrical input can be directly controlled by adjustment of the field current. If the field current is increased beyond the value required to provide the magnetic field, the stator current changes to include a component to compensate for this overmagnetization. The result will be a total stator current that leads the stator voltage in phase, thus providing to the power system reactive volt-amperes needed to magnetize other apparatuses, such as transformers and induction motors. Operation of a large synchronous motor at such a leading power factor may be an effective way of improving the overall power factor of the electrical loads in a manufacturing plant to avoid additional electric supply rates that may otherwise be charged for low power-factor loads.

Applications of three-phase synchronous motors

Three-phase synchronous motors find their major application in industrial situations where there is a large, reasonably steady mechanical load, usually in excess of 300 kilowatts, and where the ability to operate at leading power factor is of value. Below this power level, synchronous machines are generally more expensive than induction machines. In some instances, a synchronous machine is installed for the sole purpose of improving overall plant power factor. In this case, it is called a synchronous capacitor because it provides the same power factor correction as capacitors connected across the supply line.

The field current may be supplied from an externally controlled rectifier through slip rings, or, in larger motors, it may be provided by a shaft-mounted rectifier with a rotating transformer or generator.

A synchronous motor with only a field winding carrying a direct current would not be self-starting. At any speed other than synchronous speed, its rotor would experience an oscillating torque of zero average value as the rotating magnetic field repeatedly passes the slower moving rotor. Normally, a short-circuited winding similar to that of an induction machine is added to the rotor to provide starting torque, as shown in Figure 60. The motor is started, either with full or reduced stator voltage, and brought up to about 95 percent of synchronous speed, usually with the field winding short-circuited to protect it from excessive induced voltage. The field current is then applied and the rotor pulls into synchronism with the revolving field.

This additional rotor winding is usually referred to as a damper winding because of its additional property of damping out any oscillation that might be caused by sudden changes in the load on the rotor when in synchronism. Adjustment to load changes involves changes in the angle by which the rotor field lags the stator field and thus involves short-term changes in instantaneous speed. These cause currents to be induced in the damper windings, producing a torque that acts to oppose the speed change.

Protection for synchronous motors is similar to that employed with large induction motors. Temperature may be sensed in both the stator and field windings and used to switch off the electric supply. Considerable heating occurs in the rotor-damper winding during starting, and a timer is frequently installed to prevent repeated starts within a limited time interval.

Permanent-magnet motors. The magnetic field for a synchronous machine may be provided by using permanent magnets rather than a field winding. This eliminates the need for slip rings and an external source of field current and provides a simple rugged rotor. The motor does not, however, have a means of controlling the stator power factor.

Use in variable-speed drives

The rotor can be of the form shown in Figure 50 with radially directed magnets made of neodymium-boron-iron, samarium-cobalt, or ferrite. The machine in the figure does not contain a damper winding and thus cannot be started on a constant-frequency supply. The main application for a motor of this type is in variable-speed drives

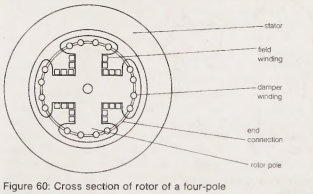

Figure 60: Cross section of rotor of a four-pole synchronous motor.

where the stator is supplied from a variable-frequency, variable-voltage source. Where starting capability is required, the magnets are imbedded in the rotor iron and a damper winding is placed in slots in the rotor surface (see Figure 60).

An alternative form of permanent-magnet motor is shown in Figure 61. Circumferentially directed magnets provide flux to iron poles, which in turn set up a radial field in the air gap. This form is particularly suitable for small motors using ferrite magnets.

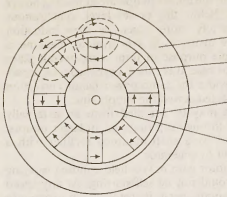

Figure 61: Cross section of an eight-pole synchronous motor with circumferentially directed permanent magnets.

Hysteresis motors. A distinctive feature of synchronous motors is that the speed is uniquely related to the supply frequency. As a result, several special types of synchronous motors have found wide application in devices such as clocks, tape recorders, and phonographs. One of the most extensively used is the hysteresis motor in which the rotor consists of a ring of a semi-permanent magnet material like a high-carbon steel. At full speed, the motor operates as a permanent-magnet machine. If the speed is reduced by pulling the rotor out of synchronism, the stator field causes the rotor material to be cyclically magnetized around its hysteresis loop, resulting in a rotor field that lags the stator field by a few degrees and continues to produce torque. These motors provide good starting torque and are very quiet. Their efficiency is low, and applications are restricted to small power ratings.

Reluctance motors. Machines of this kind operate on the principle that forces are established tending to minimize the volume of any air gap in an iron system carrying a magnetic field. One of the forms of a reluctance motor is shown in cross section in Figure 62. The rotor consists of four iron poles with no electrical windings. The stator has six poles each with a current-carrying coil. In the condition represented in the figure, current has just been passed through coils a and a', producing a torque on the rotor aligning two of its poles with those of the a-a' stator. The current is now switched off in coils a and a' and switched on to coils b and b'. This produces a counterclockwise torque on the rotor aligning two rotor poles with stator poles b and b'. This process is then repeated with stator coils c and c' and then with coils a and a'. The torque is dependent on the magnitude of the coil currents but is independent of its polarity. The direction of rotation can be changed by changing the order in which the coils are energized.

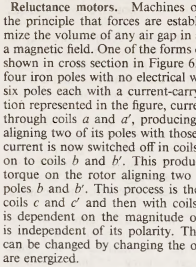

Figure 62: A reluctance motor in cross section.

The currents in the stator coils are usually controlled by semiconductor switches connecting the coils to a direct voltage source. A signal from a position sensor mounted on the motor shaft is used to activate the switches at the appropriate time instants. Frequently a magnetic sensor based on the Hall effect is employed. (The Hall effect involves the development of a transverse electric field in a semiconductor material when it carries a current and is placed in a magnetic field perpendicular to the current.) The overall system is known as a self-synchronous motor drive. It can operate over a wide and controlled speed range.

Self-synchronous motor drive

There are several other configurations for reluctance motors. In one form, the rotor consists of an iron ring with radial cuts or slots through it. A p-pole rotor has p sectors, or arcs. The magnetic flux travels circumferentially around the arc of this rotor ring, completing the path between adjacent stator poles.

In another form, the rotor has salient poles of the configuration shown in Figure 60 but without the field windings. The stator is cylindrical and contains a three-phase winding connected to a constant-frequency supply. A damper winding is fitted in the rotor surface so that the machine can start as an induction motor. After the rotor pulls into synchronism with the rotating field of the stator, it operates as a synchronous motor at constant speed.

Single-phase synchronous motors. A revolving field can be produced in synchronous motors from a single-phase source by use of the same method as for single-phase induction motors. With the main stator winding connected directly to the supply, an auxiliary winding may be connected through a capacitor, as in Figure 56. Alternatively, an auxiliary winding of a higher resistance can be employed, as in Figure 57. For small clock motors, the shaded-pole construction of the stator is widely used in combination with a hysteresis-type rotor (see above). The efficiency of these motors is very low, usually less than 2 percent, but the cost is low as well.

Direct-current commutator motors. A sketch of an elementary form of DC motor is provided in Figure 51. A stationary magnetic field is produced across the rotor by poles on the stator. These poles may be encircled by field coils carrying direct current, or they may contain permanent magnets. The rotor or armature consists of an iron core with a coil accommodated in slots. The ends of the coil are connected to the bars of a commutator switch mounted on the rotor shaft. Stationary graphite brushes lead to external terminals.

Components and characteristics

Suppose a direct-current supply is connected to the armature terminals such that a current enters at the positive terminal shown in Figure 51. This current interacts with the magnetic flux to produce a counterclockwise torque, which in turn accelerates the rotor. When the rotor has turned about 120° from the position shown in the figure, the connection from the supply to the armature coil is reversed by the commutator. The new direction of the current in the armature coil is such as to continue to produce counterclockwise torque. As the rotor rotates in a counterclockwise direction, a voltage proportional to the speed is generated in the armature coil (see *Direct-current generators* above). While this coil voltage is alternating, the commutator action produces a unidirectional voltage at the motor terminals with the polarity shown. The electrical input will be the product of this terminal voltage and the input current. The mechanical output power will be the product of the rotor torque and speed.

In a practical DC motor, the armature winding consists of a number of coils in slots, each spanning $1/p$ of the rotor periphery for p poles. In small motors the number of coils may be as low as six, while in large motors it may be as large as 300. The coils are all connected in series, and each junction is connected to a commutator bar, as indicated in Figure 63. If current enters at the positive brush, the coil currents have the directions shown. All coils under the poles contribute to torque production.

The motor in Figure 63 contains two poles made of ferrite permanent-magnet material. This structure is typical of small DC motors such as those used in automobile fans. When higher torque is required, as, for example, in

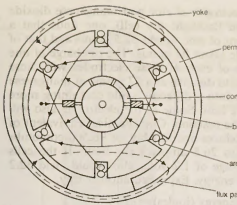

Figure 63 Direct-current commutator motor with a permanent-magnet field.

the starter motor of an automobile, stronger magnets such as neodymium-iron-boron may be employed. When the terminals of this motor are connected to a constant direct-voltage source, such as a battery, the initial current will be limited only by the resistance of the armature winding and the brushes. The torque produced by the interaction of this current with the field accelerates the rotor. A voltage is generated in the winding proportional to the speed. This voltage opposes that of the source, thus reducing the current and the torque. With no mechanical load, the generated voltage will rise to a value nearly equal to the source voltage, allowing just enough current to provide for friction torque. Application of a load torque slows down the rotor, decreasing the generated voltage, increasing the current, and producing torque to match the load torque.

With larger motors, the armature winding resistance is too low to limit the current on starting to a value that can be switched by the commutator. These motors are normally started with a resistance connected in series to the armature supply. This resistance is usually decreased in stages as the speed increases.

Speed-adjustment capability

The permanent-magnet commutator motor of Figure 63 has no provision for speed control when attached to a constant-voltage supply. If speed adjustment is desired, the permanent-magnet field can be replaced by iron poles with field coils. These coils can be provided with current from the same supply as for the armature or from a separate supply. A variable series resistor can be used to adjust the field current. With maximum field current and thus maximum magnetic flux, the generated voltage will equal the supply voltage at a minimum value of no-load speed. As load is added, the speed will reduce somewhat and the armature current will increase to produce the required torque. If the field current is reduced, the motor will have to rotate faster through the reduced flux to generate the same voltage. The no-load speed will be increased. For a given rated armature current, the available torque will be reduced because of the reduced flux. The motor, however, will be able to provide the same mechanical power at a higher speed and lower torque.

Shunt motors

Commutator motors with adjustable field current are known as shunt motors, or separately excited motors. Normally, the available speed range is less than 2 to 1, but special motors can provide a speed range of up to 10 to 1.

Another form of commutator motor is the series motor in which the field coils, with relatively few turns, carry the same current as does the armature. With a high value of current, the flux is high, making the torque high and the speed low. As the current is reduced, the torque is reduced and the speed increases. In the past, such motors were widely used in electric transportation vehicles, such as subway trains and fork-lift trucks.

Large DC motors usually have four or more poles to reduce the thickness of the required iron in the stator yoke and to reduce the length of the end connections on the armature coils. These motors may also have additional small poles, or interpoles, placed between the main poles and have coils carrying the supply current. These poles are placed so as to generate a small voltage in each armature coil as it is shorted out by the commutator. This assists the quick reversal of current in the coil and prevents commutator sparking.

DC commutator motors have been extensively used in steel mills, paper mills, robots, and machine tools where accurate control of speed or speed reversal, or both, are required. The field is supplied from a separate voltage source, usually with constant field current, or from permanent magnets. The armature is supplied from a source of controllable voltage. The speed is then approximately proportional to the source voltage. Reversal of the armature supply voltage at a controlled rate reverses the motor.

Alternating-current commutator motors. A specially designed series-commutator motor may be operated from a single-phase alternating voltage supply. When the supply current reverses, both the magnetic field and the armature current are reversed. Thus, the torque remains in the same direction. These motors are often called universal motors because they may be used with either a direct-voltage supply or with a 60-hertz alternating-voltage supply. They have wide application in such small domestic appliances as mixers, portable tools, and vacuum cleaners.

Universal motors

DEVELOPMENT OF ELECTRIC GENERATORS AND MOTORS

Within a year of Michael Faraday's discovery of electromagnetic induction (1831), a small hand generator was demonstrated in Paris, and by 1850 generators were being manufactured in several countries. These early generators were little more than assemblies of coils and permanent magnets that could be maintained in relative motion. Further developments of significance did not appear until the experimental work of William Sturgeon of England and of Joseph Henry and Thomas Davenport of the United States led to the manufacture of practical electromagnets. This technological advance contributed much to the development of practical electrical machines.

The French engineer and inventor Zénobe-Théophile Gramme built the first truly commercial electric motor, which he demonstrated in 1873. Using iron-cored electromagnets and an iron ring armature surrounded by a winding, Gramme produced a practical, efficient machine that could be used either as a motor or as a generator. His machine was of the DC commutator type. It provided the basis for early DC electric supply.

First electric motor of commercial significance

The first significant AC motor was patented by the Serbian-American inventor Nikola Tesla in 1888. Tesla's motor was able to utilize the two- and three-phase alternating-current supplies that were becoming readily available at the time. Its principle of operation provides the basis for the majority of electric motors produced today. (G.R.Sl.)

Direct energy-conversion devices

BATTERIES

General characteristics. A battery is a simple device that converts chemical energy directly to electrical energy. It consists of two or more galvanic, or electrochemical, cells that produce direct-current electricity. The term battery is also commonly applied to a single galvanic cell. Every battery (or cell) has a cathode, or positive electrode, and an anode, or negative electrode. These electrodes must be separated by and are often immersed in an electrolyte that permits the passage of ions between the electrodes (Figure 64). The electrode materials and electrolyte are chosen and arranged so that sufficient electromotive force (voltage) and electric current (amperes) can be developed between the terminals of a battery to operate lights, machines, or other devices. Since an electrode contains only a limited number of units of chemical energy convertible to electrical energy, it follows that a battery of a given size has a certain capacity to operate devices and will eventually become exhausted. The active parts of a battery are usually encased in a box (or jacket) and cover system that keeps air outside and the electrolyte solvent inside and that provides a structure for the assembly.

Battery usefulness is limited not only by capacity but also by how fast current can be drawn from it. The salt ions chosen for the electrolyte solution must be able to move fast enough through the solvent to carry chemical matter between the electrodes equal to the rate of electrical demand. Battery performance is thus limited by the diffusion rates of internal chemicals as well as by capacity.

Factors that affect battery performance

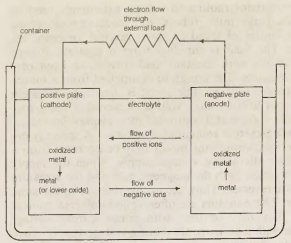

Figure 64: Basic components of an electrochemical cell.

The voltage of an individual cell and the diffusion rates inside it are both reduced if the temperature is lowered from a reference point, such as 21° C. If the temperature falls below the freezing point of the electrolyte, the cell will usually produce very little useful current and may actually change internal dimensions, resulting in internal damage and diminished performance even after it has warmed up again. If the temperature is raised deliberately, faster discharge can be sustained, but this is not generally advisable because the battery chemicals may evaporate or react spontaneously with one another, leading to early failure.

Beyond the technical factors so far discussed, it must be recognized that commercially available batteries are designed and built with market factors in mind. The quality of materials and the complexity of electrode and container design are reflected in the market price sought for any specific product. As new materials are discovered or the properties of traditional ones improved, however, the typical performance of even older battery systems sometimes increases by large percentages.

Batteries are divided into two general groups: (1) primary batteries and (2) secondary, or storage, batteries. Primary batteries are designed to be used until the voltage is too low to operate a given device and then discarded. Secondary batteries have many special design features, as well as particular materials for the electrodes, that permit them to be reconstituted (recycled). After partial or complete discharge, they can be recharged by DC voltage and current to their original state. While this original state is usually not restored completely, the loss per cycle in commercial batteries is only a small fraction of 1 percent even under varied conditions.

Anode and cathode composition

Principles of operation. The anode of an electrochemical cell (Figure 64) is usually a metal that is oxidized (gives up electrons) at a potential between 0.5 volt and about four volts above that of the cathode. The cathode generally consists of a metal oxide or sulfide that is converted to a less-oxidized state by accepting electrons, along with ions, into its structure. A conductive link via an external circuit (*e.g.*, a lamp or other device) must be provided to carry electrons from the anode to the negative battery contact. Sufficient electrolyte must be present as well. The electrolyte consists of a solvent (water, an organic liquid, or even a solid) and one or more chemicals that dissociate into ions in the solvent. These ions serve to deliver electrons and chemical matter through the cell interior to balance the flow of electric current outside the cell during cell operation.

The fundamental relationship of electrochemical cell operation put forth by Faraday in 1834 is that for every ampere that flows for a period of time a matching chemical reaction or other change must take place. The extent of these changes is dependent on the molecular and electronic structure of the elements comprising the battery electrodes and electrolyte. Secondary changes may also occur, but a primary pair of theoretically reversible reactions must take place at the electrodes for electricity to be produced. The actual DC power generated by a battery is measured by the number of amperes produced × the unit of time × the average voltage over that time.

For a cell with electrodes of zinc and manganese dioxide (*e.g.*, the common flashlight dry cell), one finds that a chemical equivalent of zinc weighs 32.5 grams and that of manganese dioxide about 87 grams. The discharge of one equivalent weight of each of these electrodes will cause 32.5 grams of zinc to dissolve and 87 grams of manganese dioxide to change into a different oxide containing more hydrogen and zinc ions. Some of the electrolyte also will be consumed in the reaction. One chemical equivalent of each electrode produces one faraday, or 96,500 coulombs of current equal to 26.8 amperes per hour. If the cells operate at an average of 1.2 volts, this would yield 32.2 watt-hours of DC energy. Expressed another way,

$$\text{Energy (joules)} = nFV,$$

where n equals the number of chemical equivalents discharged, F is the Faraday constant (9.648×10^4 coulombs per mole), and V is the average (not necessarily constant) voltage of the cell for the period of the discharge.

There is a large number of elements and compounds from which to select potentially useful combinations for batteries. The commercial systems in common use represent the survivors of numerous tests where continued use depended on adequate voltage, high current-carrying capacity, low-cost materials, and tolerance for user neglect. Better sealing technology and plastics are making further development of all cell systems possible, but particularly those using very active lithium for the anode. This situation has yielded commercial cells with as much as 3.6 volts on load and very high current-carrying capability.

Primary batteries. *Zinc-manganese dioxide systems.* These cell systems are the most commonly used worldwide in flashlights, toys, radios, tape recorders, and flash cameras. There are three variations: the Leclanché cell, the zinc chloride cell, and the alkaline cell. All provide an initial voltage of 1.58 to 1.7 volts, which declines with use to an end point of about 0.8 volt. The Leclanché cell (Figure 65) is the least expensive, traditional general-purpose dry cell available nearly everywhere. Invented by the French engineer Georges Leclanché in 1866, it immediately became a commercial success in large sizes because of its readily available low-cost constituent materials. The anode of this primary cell is a zinc alloy sheet or "cup," the alloy containing small amounts of lead, cadmium, and mercury. The electrolyte consists of a saturated aqueous solution of ammonium chloride containing roughly 20 percent zinc chloride. The cathode is made of impure manganese dioxide (usually mined from selected deposits in Africa, Brazil, or Mexico). This compound is blended with carbon black and electrolyte to create a damp, active cathode mixture which is formed around a carbon collector rod, also called an electrode. All cells of this type are provided with an overwrap structure with metal covers for electrical contact.

Leclanché cell

While first patented in 1899, the zinc chloride cell is really a modern adaptation of the Leclanché cell. Its commercial success is attributable in part to the development of plastic seals that has made it possible to largely dispense with the use of ammonium chloride (Figure 66).

Zinc chloride cell

From G. Vinal, *Storage Batteries* (© 1951); John Wiley & Sons, Inc.

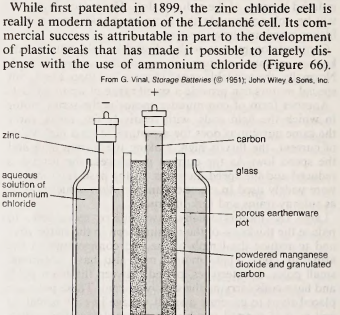

Figure 65: Georges Leclanché's cell.

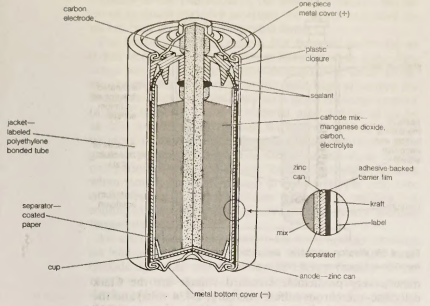

Figure 66: *Modern version of the Leclanché cell.* This heavy-duty carbon–zinc primary battery is a dry cell with an immobilized electrolyte.
By courtesy of Eveready Battery Co., Inc.

The manganese dioxide of the cathode is usually a blend of synthetic manganese dioxide of high purity with natural varieties. The zinc chloride cell is capable of greater continuous service than the Leclanché cell, particularly in motorized devices such as toys. Its use is also increasing because it can provide satisfactory performance without mercury in the zinc alloy.

Alkaline cell

The highest power density (watts per cubic centimetre) of the zinc–manganese dioxide cells is found in cells with an alkaline electrolyte, which permits a completely different type of construction, as illustrated in Figure 67. These cells became commercially available during the 1950s. A cathode of a very pure manganese dioxide–graphite mixture and an anode of a powdered zinc alloy are associated with a potassium hydroxide electrolyte and housed in a steel can. Whereas the zinc of alkaline cells formerly contained 6 to 8 percent mercury, that of present-day versions contains as little as 0.15 percent so as to reduce the environmental impact of disposal. These cells, moreover, provide higher capacity to operate flashlights, toys, cassette players, and radios than either of the other two zinc–manganese dioxide systems discussed above.

Magnesium–manganese dioxide cell. This system functions well for specialized applications. It is much like the zinc chloride cell but has 0.3 volt more per cell. Magnesium–manganese dioxide cells have a long shelf life, high energy density, and are lightweight, making them especially attractive for use as power packs for portable military radios. The one drawback of these cells is that they do not function nearly as well at below-freezing temperatures as at higher temperatures.

Mercuric oxide–zinc cell. This is an alkaline-electrolyte battery system. It has long been used in the form of button-sized cells (Figure 68) for hearing aids and watches. Its energy density (watt-hours per cubic centimetre) is approximately four times greater than that of the alkaline zinc–manganese dioxide cell. Since the mercuric oxide–zinc cell provides an extremely reliable 1.35 volts, it serves as a standard reference cell.

Silver oxide–zinc cell. Another alkaline system, this cell features a silver oxide cathode and a powdered zinc anode. Because it will tolerate relatively heavy current load pulses and has a high, nearly constant, 1.5-volt operating voltage, the silver oxide–zinc cell is commonly used in watches, cameras, and hearing aids. In spite of its high cost, the outstanding current-carrying capability of this cell has resulted in its use as military torpedo batteries. Miniature cells can be obtained with either divalent silver oxide or monovalent silver oxide, the former usually having somewhat higher capacity.

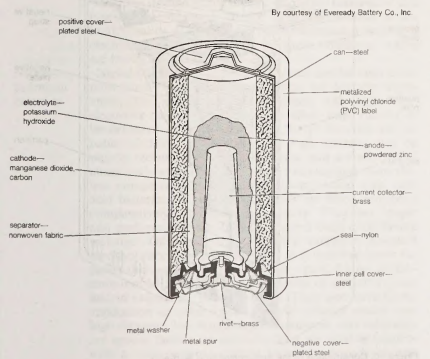

Figure 67: Alkaline zinc–manganese dioxide power cell.

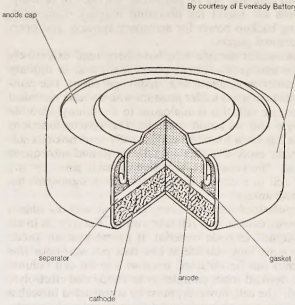

Figure 68: Typical construction of a miniature power cell, as, for example, a silver oxide–zinc or mercuric oxide–zinc system.

Lithium cells. The area of battery technology that has attracted the most research in recent years is a class of cells with a lithium anode. Because of the high chemical activity of lithium, nonaqueous (organic or inorganic) electrolytes have to be used. Such electrolytes include selected solid crystalline salts (see below). This whole new science has encouraged the commercial production of cells having no space between the anode and the liquid cathode, an unlikely condition for success in aqueous systems. A stable protective layer automatically forms on the lithium but breaks down on discharge to permit high-current operation at nearly constant voltages near 3.6 volts. By traditional measures, this allows very high power density and energy density. Lithium cells are especially attractive for use in certain aerospace applications, terrestrial portable military equipment, and such civilian applications as personal paging systems, heart pacers, and automated cameras.

Major types of lithium batteries

Lithium–iron sulfide cells in miniature sizes offer high capacity and low cost for light loads. In operations requiring 1.5 to 1.8 volts, they are a potential substitute for some silver oxide–zinc cells. In constructions where the electrodes consist of rolled up ("jelly roll") strips like those of small nickel–cadmium cells, higher power density is obtained while still retaining high capacity for premium general-purpose use. A typical electrolyte might be lithium tetrafluoborate salt in a solvent mixture of propylene carbonate, 2-methyl-2-oxazolidone, and dimethoxyethane.

Lithium–manganese dioxide cell systems have slowly gained increasingly wider application in small appliances.

Cells of this kind have an operating voltage of 2.8 volts each and offer high energy density and relatively low cost compared to some other lithium cell possibilities.

The lithium–carbon monofluoride system has been among the more successful early commercial lithium cells. It has been used extensively in cameras and smaller devices, providing about 3.2 volts per cell, high power density, and long shelf life. Good low-temperature performance and a flat voltage–time discharge relationship are provided as well. The cost of carbon monofluoride (CF_x) is high, however.

Lithium–thionyl chloride cells provide the highest energy density and power density commercially available. Thionyl chloride serves not only as the electrolyte solvent but also as the cathode material. A runaway reaction between the lithium anode and the adjacent liquid cathode material is prevented by the formation of a film of lithium chloride salt on the lithium. The electrical contact and reaction centre of the cathode are composed of porous pressed and bonded carbon powder. The performance of this type of cell system at room temperature is very impressive. Moreover, the cell can operate at −54° C, well below the point where aqueous systems function. Because of its high energy density, the lithium–thionyl chloride cell must be used with care and not be burned or disposed of casually. Such cells are useful for powering military equipment, providing backup power for aerospace systems, and operating personal pagers.

Lithium–sulfur dioxide cells have been used extensively for some emergency-aircraft power units and in military cold-weather applications (*e.g.*, radio operation). The cathode consists of a gas under pressure with another chemical as electrolyte salt; this is analogous to the thionyl chloride electrolyte and its liquid cathode. The system functions well but has been found to occasionally vent noxious sulfur dioxide, especially after cold discharge and subsequent warm-up. The release of corrosive or toxic gases by any type of cell in a closed space constitutes a significant design disadvantage.

Air-depolarized cells. A very practical way to obtain high energy density in a cell is to employ the oxygen in air for a "liquid" cathode material. If paired with an anode such as zinc, long cell life at low cost per watt-hour (for a dry cell) can be obtained because a given cell volume may be devoted more completely to anode and electrolyte material. The cell, however, must be constructed in such a way that the oxygen is prevented from reaching the anode, which it will attack.

Zinc–air cells

Zinc–air systems are commercially available in the form of very small cells and relatively large boxlike batteries. Their principle and design are simple, but the actual batteries are, from a technical standpoint, difficult to manufacture. The "air electrode" is extremely thin and usually has a waterproof polymer-bonded porous carbon layer with a metal mesh reinforcement. A catalyst and a booster oxide may be included with the carbon to render oxygen more effectively active. The sealing of the edges of the composite electrode film and electrolyte proofing of the pores have been achieved with fluorocarbons and plastics. Fundamental improvements in electrode assembly, cell seal, and vent designs continue to be sought in scientific and engineering studies.

Aluminum–air cells have not been a commercial success to date, but their light weight and potentially high energy density have attracted much government support in the United States. Research efforts have been concentrated on developing better aluminum alloys and techniques to resist corrosion during shelf storage while at the same time providing electricity at instant demand. Similarly, inhibitors for inclusion in the alkaline electrolyte are under study. Aluminum–air cells also are being considered for applications in which the metal anode, the electrolyte, and the reaction products are mechanically removed and replaced to create a kind of fuel cell (see *Fuel cells* below). If stability and cell design problems can be overcome, this system may very well prove attractive for many applications, including use in electric cars or trucks.

Other primary battery systems. Many other cell types are in use on a small scale. For example, cells that produce a very predictable standard voltage are the Clark cell (zinc–mercurous sulfate–mercury; 1.434 volts) and the Weston cell (cadmium–mercurous sulfate–mercury; 1.019 volts). For the construction of the latter, see Figure 69. Magnesium–silver chloride and magnesium–lead chloride batteries are commonly employed in undersea operations where the salt water becomes the electrolyte when the battery is submerged.

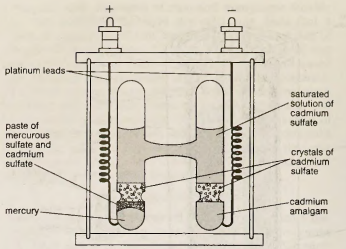

Figure 69: Weston normal or saturated standard cell.
From G. Vinal, *Storage Batteries* (© 1951), John Wiley & Sons, Inc.

An important new group of cells consists of systems with a solid electrolyte in which the mixture of compounds is such that cell ions can slowly move from site to site in the electrolyte crystal structure. Examples include silver–silver rubidium iodide–iodine cells and lithium–lithium iodide–lead iodide mixtures. Batteries with ion-containing polymers are being studied extensively. In such devices, electrode conductivity is achieved by special polymer structure and doping with charged ions either chemically or electrically.

Storage batteries. *Lead secondary cells.* The so-called lead-acid secondary battery has long been the most widely used rechargeable portable power source. Most such batteries are constructed of lead plates, or grids, where one of the grids, the positive electrode, is coated with lead dioxide in a particular crystalline form, along with additives such as calcium lignosulfate (Figure 70). The electrolyte, composed of sulfuric acid, participates in the electrode reactions where lead sulfate is formed and carries current in moving ions. Recent estimates show that in terms of

Components of lead-acid batteries

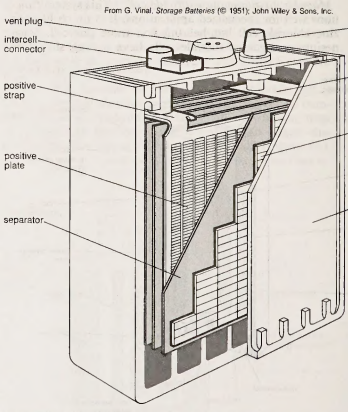

Figure 70: Construction of the automotive-type lead-acid battery (cutaway view).

capacity in use (watt-hours), the lead-acid battery has 20 times as much capacity as either the nickel–cadmium or nickel–iron alkaline rechargeable battery.

The lead-acid battery system has been as successful as it has because of the following features: wide capability range for high or low current demand over usual ambient temperatures; good cycle life with high reliability for hundreds of cycles, especially with good recharge control (a gram of positive active material may deliver as many as 100 ampere-hours during the service life of such a battery); relative low cost (lead is less expensive per kilogram or per ampere-hour than nickel, cadmium, or silver); comparatively good shelf life for a rechargeable system when stored; high cell voltage at 2.04 volts per cell; ease of fabricating lead components by casting, welding, or rolling; and a high degree of salvageability at low melting temperatures.

An area of continued interest for investigators working on lead-acid batteries is reduction of battery weight. Lead dioxide and lead have the lowest energy density of the major electrode materials in wide use, and they are rarely discharged in a highly efficient manner. At low rates of discharge, only about 60 percent of the active materials are cycled, and on short, 10-minute heavy loads utilization can fall to 10 percent.

Types of lead-acid batteries

Lead-acid batteries are generally classified into three groups: (1) starting–lighting–ignition (SLI) batteries, (2) traction batteries, and (3) stationary batteries. The automotive SLI battery is the best known portable rechargeable power source. High current can be obtained for hundreds of shallow-depth discharges over a period of several years. Traction batteries are employed in industrial lift trucks, delivery trucks, and other vehicles. While some are readily portable, others may weigh several tons. The great weight often serves to stabilize the vehicle during operation. Stationary batteries are now much more common than was once the case. These batteries have heavier grid structures and other features to give them long shelf life. They are used to power emergency lights and in uninterruptible power systems for hospitals, factories, and telephone exchanges.

In a lead-acid battery the active material of the positive electrode, lead dioxide, combines with the electrolyte, sulfuric acid, to produce lead sulfate and water during discharge. At the negative electrode the constituent lead combines with the sulfuric acid ions to produce lead sulfate and hydrogen ions, thereby replacing the hydrogen ions consumed at the positive electrode. The water formed and the loss of sulfate dilutes the electrolyte, lowering its density. Because of this, the state of charge of a lead-acid battery can be determined from the specific gravity of the electrolyte.

Alkaline storage batteries. In secondary batteries of this type, electric energy is derived from the chemical action in an alkaline solution. Such batteries feature a variety of electrode materials, some of the more notable of which are briefly discussed in this section.

Nickel–cadmium batteries

Nickel (hydroxide)–cadmium systems are the most common small rechargeable battery type for portable appliances. The sealed cells are equipped with "jelly roll" electrodes (see Figure 71), which allow high current to be delivered in an efficient way. These batteries are capable of delivering exceptionally high currents, can be rapidly recharged hundreds of times, and are tolerant of abuse such as overdischarging or overcharging. Nonetheless, compared to many primary batteries and even lead-acid batteries, nickel–cadmium cells are heavy and have comparatively limited energy density. They last longer and perform better if fully discharged each cycle before recharge. Otherwise, the cells may exhibit a so-called memory effect where they behave as if they had lower capacity than was built into the battery pack. Larger nickel–cadmium batteries are used for starting up aircraft engines and in emergency power systems. They also have found application in other backup power systems where very high currents, low temperature conditions, and reliability are special factors. In addition, they are used in tandem with a solar-powered current source to provide electric power at night.

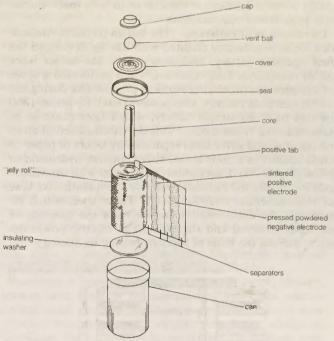

Figure 71: Nickel (hydroxide)–cadmium cell of "jelly roll" construction (see text).
By courtesy of Eveready Battery Co., Inc.

Nickel (hydroxide)–zinc cells are attractive from a development viewpoint. If their cycle life can be significantly improved, systems of this sort may become a viable substitute for nickel–cadmium cells or lead-acid traction batteries.

Nickel (hydroxide)–iron batteries can provide thousands of cycles but do not recharge with high efficiency, generating heat and consuming more electricity than is generally desirable. They have been used extensively in the European mining industry, however.

Nickel–hydrogen batteries

Nickel (hydroxide)–hydrogen cells were developed primarily for the U.S. space program. Research has shown that such alloys as lanthanum-nickel in certain proportions will reversibly dissolve or release hydrogen in proportion to changes in pressure and temperature. This hydrogen can serve as an active anode material. There is speculation that nickel–hydrogen batteries may replace nickel–cadmium batteries in many applications.

Alkaline zinc–manganese dioxide rechargeable cells have been developed as a substitute for other systems that provide moderate amounts of electricity for certain applications. Their high energy density and low cost encourage further engineering work and commercial introduction.

Silver (oxide)–zinc batteries are expensive but are employed where high power density, good energy-cycling efficiency, low weight, and low volume are critical. After years of use in torpedoes and mines, they have more recently become important in special vehicles for underwater tests and submarine exploration. They also are employed in portable radar units and communications equipment, as well as in aircraft and space vehicles.

Lithium secondary cells. These show considerable promise since their theoretical energy densities can range from 600 to 2,000 watt-hours per kilogram. Even after allowance is made for the inactive parts of such a cell, the net energy density is still competitive with aqueous systems. Systems of this type receiving developmental attention include lithium–titanium disulfide, lithium–manganese dioxide, and lithium–molybdenum disulfide. Much current research is devoted to developing better oxide and sulfide structures, better solvent combinations, and better and safer constructions.

Sodium–sulfur storage batteries. Much experimental work has been expended on this type of high-temperature system, which operates at 350° C. Many problems related to material stability have to be solved before a completely satisfactory system can be produced. This is particularly true given the need to tolerate cooling and heating the whole battery between uses. Yet, the ready availability of sodium and sulfur, low cost, and ability of each cell to deliver 2.3 volts make this system extremely attractive. It

could be used for electric vehicles or to help meet municipal peak power requirements.

Development of batteries. The Italian physicist Alessandro Volta is generally credited with having developed the first operable battery. Following up on the earlier work of his compatriot Luigi Galvani, Volta performed a series of experiments on electrochemical phenomena during the 1790s (see ELECTRICITY AND MAGNETISM). By about 1800 he had built his simple battery, which later came to be known as the "voltaic pile." This device consisted of alternating zinc and silver disks separated by layers of paper or cloth soaked in a solution of either sodium hydroxide or brine (Figure 72). Experiments performed with the voltaic pile eventually led Faraday to derive the quantitative laws of electrochemistry (about 1834). These laws, which established the exact relationship between the quantity of electrode material and the amount of electric power desired, formed the basis of modern battery technology.

The voltaic pile

From G. Vinal, *Primary Batteries* (© 1950), John Wiley & Sons, Inc., after the *Philosophical Transactions of the Royal Society* (1800)

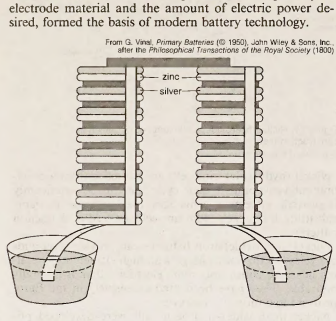

Figure 72: Alessandro Volta's (top) pile and (bottom) crown of cups.

Various commercially significant primary cells were produced on the heels of Faraday's theoretical contribution. In 1836 John Frederic Daniell, a British chemist, introduced an improved form of electric cell consisting of copper and zinc in sulfuric acid. The Daniell cell was able to deliver sustained currents during continuous operation far more efficiently than Volta's device.

Further advances were effected in 1839 by William Robert Grove with his two-fluid primary cell consisting of amalgamated zinc immersed in dilute sulfuric acid, with a porous pot separating the sulfuric acid from a strong nitric acid solution containing a platinum cathode. The nitric acid served as an oxidizing agent, which prevented voltage loss resulting from an accumulation of hydrogen at the cathode. The German chemist Robert Wilhelm Bunsen substituted inexpensive carbon for platinum in Grove's cell and thereby helped promote its wide acceptance.

First practical storage battery

In 1859 Gaston Planté of France invented a lead-acid cell, the first practical storage battery and the forerunner of the modern automobile battery. Planté's device was able to produce a remarkably large current, but it remained a laboratory curiosity for nearly two decades.

Georges Leclanché's prototype of the zinc–manganese dioxide system paved the way for the development of the modern primary cell. The original version of the Leclanché cell was "wet," as it had an electrolyte consisting of a solution of ammonium chloride. The idea of employing an immobilized electrolyte was finally introduced in the late 1880s and launched the dry-cell industry that continues to flourish today.

The invention of alkaline electrolyte batteries (specifically storage batteries of the nickel–cadmium and nickel–iron type) between 1895 and 1905 provided systems that could furnish much-improved cycle life for commercial application. The 1930s and '40s saw the development of the silver oxide–zinc and mercuric oxide–zinc alkaline cells, systems that provided the highest energy yet known per unit weight and volume. Since midcentury, advances in construction technology and the availability of new materials have given rise to smaller yet more powerful batteries suitable for use in a wide array of portable equipment. Perhaps most notable have been the entrance of lithium batteries into the commercial market and the development of nickel–hydrogen cells for use in spacecraft.

FUEL CELLS

General characteristics. A fuel cell is an electrochemical device that converts the chemical energy of a fuel directly and efficiently to direct-current electricity in a continuous manner. It resembles a battery in many respects, but it can supply electrical energy over a much longer period of time. This is because a fuel cell is continuously supplied with fuel and air (or oxygen) from an external source, while a battery contains only a limited amount of fuel material and oxidant, which are depleted with use.

External source of fuel and oxidizer

A fuel cell (actually a group of cells) has essentially the same kinds of components as a battery. As in the latter, each cell of a fuel-cell system has a matching pair of electrodes (Figure 73). These are the anode, which supplies electrons, and the cathode, which absorbs electrons. Both electrodes must be immersed in and separated by an electrolyte, which may be a liquid or a solid but which must in either case conduct ions between the electrodes in order to complete the chemistry of the system. A fuel, such as hydrogen, is supplied to the anode where it is oxidized, producing hydrogen ions and electrons. An oxidizer, such as oxygen, is supplied to the cathode where the hydrogen ions from the anode absorb electrons from the latter and react with the oxygen to produce water. The difference between the respective energy levels at the electrodes (electromotive force) is the voltage per unit cell. The amount of current available to the external circuit depends on the chemical activity and amount of the substances supplied as fuels. The current-producing process continues for as long as there is a supply of reactants, for, unlike in a regular battery, the electrodes and electrolyte of a fuel cell are designed to remain unchanged by chemical reaction.

A practical fuel cell is necessarily a complex system. It must have features to boost the activity of the fuel, pumps and blowers, fuel-storage containers, and a variety of sophisticated sensors and controls with which to monitor and adjust the operation of the system. The operating capability and lifetime of each of these system design features may limit the performance of the fuel cell.

As in the case of other electrochemical systems, fuel-cell operation is dependent on temperature. The chemical activity of the fuels and the value of the activity promoters, catalysts, are reduced by low temperatures (*e.g.*, 0° C). Very high temperatures, on the other hand, improve the

Temperature-dependent operation

From R. Noyes (ed.), *Fuel Cells for Public Utility and Industrial Power* (1977), Noyes Data Corp., based on a report by United Technologies Corp. (February 1976)

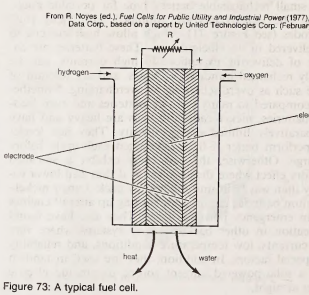

Figure 73: A typical fuel cell.

activity factors but may reduce the functioning lifetime of electrodes, blowers, construction materials, and sensors. Each type of fuel cell thus has an operating-temperature design range, and a significant departure from this range is likely to diminish both capacity and lifetime.

A fuel cell, like a battery, is inherently a high-efficiency device. Unlike internal-combustion machines, where a fuel is burned and gas is expanded to do work, the fuel cell converts chemical energy directly into electrical energy (Figure 74). Because of this fundamental characteristic, fuel cells may convert fuels to useful energy at an efficiency as high as 60 percent, whereas the internal-combustion engine is limited to efficiencies of near 40 percent or less. The high efficiency means that much less fuel and a smaller storage container are needed for a fixed energy requirement. For this reason, fuel cells are an attractive power supply for space missions of limited duration and for other situations where fuel is very expensive and difficult to supply. They also emit no noxious gases such as nitrogen dioxide and produce virtually no noise during operation, making them contenders for local municipal power generation stations.

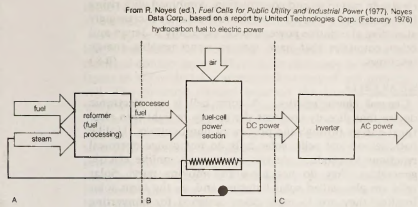

Figure 74: *Elements of a fuel-cell power plant.* (A) The reformer section processes hydrocarbon fuel for fuel-cell use. (B) The power section converts the processed fuel and air into DC power. (C) The inverter produces usable AC power to meet customer requirements.

A fuel cell can be designed to operate reversibly. In other words, a hydrogen–oxygen cell that produces water as a product can be made to regenerate hydrogen and oxygen. Such a regenerative fuel cell entails not only a revision of electrode design but also the introduction of special means for separating the product gases. Eventually power modules comprised of this type of high-efficiency fuel cell, used in conjunction with large arrays of solar thermal collectors or other solar power systems, may be utilized to keep energy-cycle costs lower in longer-lived equipment.

Regenerative fuel cells

Principles of operation. Because a fuel cell produces electricity continuously from fuel, it has many output characteristics similar to those of any other direct-current generator system. A DC generator system can be operated in either of two ways from a planning viewpoint: (1) Fuel may be burned in a heat engine to drive an electric generator, which makes power available and current flow. Or (2) fuel may be converted to a form suitable for a fuel cell, which then generates power directly.

A wide range of liquid and solid fuels may be used for a heat-engine system, while hydrogen, reformed natural gas (*i.e.,* methane that has been converted to hydrogen-rich gas), and methanol are the primary fuels available for current fuel cells. If fuels such as natural gas must be altered in composition for a fuel cell, the net efficiency of the fuel-cell system is reduced, and much of its efficiency advantage is lost. Such an "indirect" fuel-cell system would still display an efficiency advantage of as much as 20 percent. Nonetheless, to be competitive with modern thermal generating plants a fuel-cell system must attain a good design balance with low internal electrical losses, corrosion-resistant electrodes, electrolyte of constant composition, low catalyst costs, and ecologically acceptable fuels.

Available fuels

The first technical challenge that must be overcome in developing practical fuel cells is to design and assemble consistently an electrode that allows the gaseous or liquid fuel to contact a catalyst and an electrolyte at a group of solid sites that do not change very rapidly. Thus, a three-phase reaction situation is typical on an electrode that must also serve as an electrical conductor. As seen in Figure 75, such can be provided by thin sheets that have (1) a waterproof layer usually with Teflon (polytetrafluoroethylene), (2) an active layer of a catalyst (*e.g.,* platinum, gold, or a complex organometallic compound on a carbon base), and (3) a conducting layer to carry the current generated in or out of the electrode. If the electrode floods with electrolyte, the operation rate would become very slow at best. If the fuel breaks through to the electrolyte side of the electrode, the electrolyte compartment might become filled with gas or vapour, inviting an explosion should the oxidizing gas also reach the electrolyte compartment or the fuel gas enter the oxidizing gas compartment. In short, careful design, construction, and pressure control are essential in a working fuel cell to maintain stable operation. Since fuel cells have been used on Apollo lunar flights as well as on all other U.S. orbital manned space missions (*e.g.,* those of Gemini and the Space Shuttle), it is evident that all three requirements can be met reliably.

Providing a fuel-cell support system of pumps, blowers, sensors, and controls for maintaining fuel rates, electric current load, gas and liquid pressures, and fuel-cell temperature remains a major engineering design challenge. Significant improvements in the service life of these components under adverse conditions would contribute to the wider use of fuel cells.

Types of fuel cells. Various types of fuel cells have been developed. They are generally classified on the basis of the electrolyte used because the electrolyte determines the operating temperature of a system and in part the kind of fuel that can be employed.

Alkaline fuel cells. These are devices that, by definition, have an aqueous solution of sodium hydroxide or potassium hydroxide as the electrolyte. The fuel is almost always hydrogen gas, with oxygen or oxygen in air as the oxidizer. The cells generally operate at less than 100° C and are constructed of metal and certain plastics. Electrodes are made of carbon and a metal such as nickel. Product water must be removed from the system as a reaction product, usually by evaporation from the electrolyte either through the electrodes or in a separate evaporator. The operating support system presents a significant design problem. The strong, hot alkaline electrolyte attacks most polymers and tends to readily penetrate structural seams and joints. These problems have been overcome, however, and alkaline fuel cells are used on the U.S. Space Shuttle. Overall efficiencies range from 30 to 80 percent, depending on the fuel, oxidizer, and basis for the calculation.

Use on the U.S. Space Shuttle

Phosphoric acid fuel cells. Such cells have an orthophosphoric acid electrolyte that allows operation up to 200° C. They can use a hydrogen fuel contaminated with carbon dioxide and an oxidizer of air or oxygen. The electrodes consist of catalyzed carbon and are arranged in pairs set back-to-back to create a series generation circuit. The framing structure for this assembly of cells is made of graphite, which markedly raises the cost. The higher temperature and aggressive hot phosphate create struc-

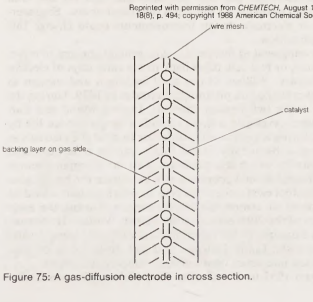

Figure 75: A gas-diffusion electrode in cross section.

tural design problems, particularly for joints, supporting pumps, and sensors. Phosphoric acid fuel cells have been proposed and tested on a limited scale for local municipal power stations and for remote-site generators.

Molten carbonate fuel cells. Fuel cells of this type operate quite differently from those so far discussed. The fuel consists of a mixture of hydrogen and carbon monoxide generated from water and a fossil fuel. The electrolyte is molten potassium lithium carbonate, which permits an operating temperature of about 650° C. In most cases, the electrodes are metallic-based, and the containment system is made of metals and special engineering plastics. (Surprisingly, such combinations of materials are anticipated to be relatively inexpensive, perhaps only three times that of the alkaline fuel cell and less than that of the phosphoric acid variety.) The cells combine the hydrogen and carbon monoxide first with the carbonate electrolyte and then with oxidizing oxygen to produce a reaction product of water vapour and carbon dioxide.

Molten carbonate fuel cells are expected to be useful in both local and larger power stations. Efficiencies of 45 percent may be attained where fossil fuels are already used. Operation at high temperatures creates a design problem for long-lived system parts and joints, especially if the cells must be heated and cooled frequently. The toxic fuel and high temperature together make power-plant safety an area of special concern in engineering design and testing as well as in commercial operation.

Solid oxide fuel cells. In some ways solid oxide fuel cells are similar to molten carbonate devices. Most of the cell materials, however, are special ceramics with some nickel. The electrolyte is an ion-conducting oxide such as zirconia treated with yttria. The fuel for these experimental cells is expected to be hydrogen combined with carbon monoxide, just as for molten carbonate cells. While internal reactions would be different in terms of path, the cell products would be water vapour and carbon dioxide. Because of the high operating temperature (800 to 1,000° C), the electrode reactions proceed very readily. As in the case of the molten carbonate fuel cell, there are many engineering challenges involved in creating a long-lived containment system for cells that operate at such a high-temperature range.

High operating temperature

Solid oxide fuel cells would be designed for use in central power-generation stations where temperature variation could be controlled efficiently and where fossil fuels would be available. The system would in most cases be associated with the so-called bottoming steam (turbine) cycle—*i.e.,* the hot gas product (at 1,000° C) of the fuel cell could be used to generate steam to run a turbine and extract more power from heat energy. Overall efficiencies of 50 to 55 percent might be possible.

Solid polymer electrolyte fuel cells. A cell of this sort is built around an ion-conducting membrane such as Nafion (trademark for a perfluorosulfonic acid membrane). The electrodes are catalyzed carbon, and several construction alignments are feasible. Solid polymer electrolyte cells function well (as attested to by their performance in Gemini spacecraft), but cost estimates are high for the total system compared to the types described above. Engineering or electrode design improvements could change this disadvantage.

Development of fuel cells. The general concept of a fuel battery, or fuel cell, dates back to the early days of electrochemistry. William Grove used hydrogen and oxygen as fuels catalyzed on platinum electrodes in 1839. During the late 1880s two English chemists, Ludwig Mond and Carl Langer, developed a fuel cell with a longer service life by employing a porous nonconductor to hold the electrolyte. It was subsequently found that a carbon base permitted the use of much less platinum, and the German chemist Wilhelm Ostwald proposed as a substitute for heat-engine generators electrochemical cells in which carbon would be oxidized to carbon dioxide by oxygen. During the early years of the 20th century Fritz Haber, Walther H. Nernst, and Edmond Bauer experimented with cells using a solid electrolyte. Limited success and high costs, however, suppressed interest in continuing developmental efforts.

From 1932 until well after World War II, Francis T. Bacon and his coworkers at Cambridge worked on creating practical hydrogen–oxygen fuel cells with an alkaline electrolyte. Research resulted in the invention of gas-diffusion electrodes in which the fuel gas on one side is effectively kept in controlled contact with an aqueous electrolyte on the other side. By mid-century O.K. Davtyan of the Soviet Union had published the results of experimental work on solid electrolytes for high-temperature fuel cells and for both high- and low-temperature alkaline electrolyte hydrogen–oxygen cells.

Invention of gas-diffusion electrodes

The need for high-efficiency stable power supplies for space satellites and manned spacecraft created exciting new opportunities for fuel-cell development during the 1950s and '60s. Molten carbonate cells with magnesium oxide pressed against the electrodes were demonstrated by J.A.A. Ketelaar and G.H.J. Broers of The Netherlands, while the very thin Teflon-bonded, carbon-metal screen catalyzed electrode was devised by other researchers. Many other technological advances, including the development of new materials, played a crucial role in the emergence of today's practical fuel cells. Further improvements in electrode materials and construction, combined with rising fuel costs, are expected to make fuel cells an increasingly attractive alternative power source, especially in Japan and other countries that have meagre nonrenewable energy resources. (B.S.)

SOLAR CELLS

General characteristics. A solar cell is an electronic device that directly converts the energy in light into electrical energy through the process of photovoltaics. Unlike batteries or fuel cells, solar cells do not utilize chemical reactions to produce electric power; and, unlike electric generators, they do not have any moving parts. Solar cells are also called solar batteries and, as the term solar implies, they are in most cases designed for converting sunlight into electrical energy.

Solar cells can be arranged into large groupings called arrays. These arrays, which may be composed of many thousands of individual cells, can function as central electric power stations in the same manner as nuclear power plants and coal- or oil-fired power plants. Such solar-cell power installations convert the energy in sunlight into electrical energy for distribution to industrial, commercial, and residential users. Solar cells in much smaller configurations, commonly referred to as solar-cell panels, are used to provide electric power in many remote terrestrial locations; they are well suited, for example, to run water pumps in desert areas and to power navigational aids at sea. Because they have no moving parts that could require service or fuels that would require replenishment, solar cells are ideal for providing power in space. As a consequence, most space satellites, including communications and weather satellites, are solar-cell powered. Since light is the basic source of the power generated by solar cells, space applications are generally limited to regions of the solar system that are close enough to the Sun to receive substantial amounts of radiant energy. Another growing application of solar cells is in consumer products, such as electronic toys, hand-held calculators, and portable radios. Solar cells used in devices of this kind may utilize indoor artificial light (*e.g.,* from incandescent and fluorescent lamps) as well as natural light from the Sun in converting radiant energy into electricity.

Arrays of solar cells

Structure and principles of operation. The basic structure of a typical solar cell, whether it is used in a central power station, a satellite, or a calculator, is shown in Figure 76. As may be seen, light enters the device through a layer of material called the antireflection layer. The function of this layer is to trap the light falling on the solar cell and to promote the transmission of this light into the energy-conversion layers below. Such materials as silicon oxides or titanium dioxide are employed as the antireflection layer in solar cells. The photovoltaic effect, which causes the cell to convert light directly into electrical energy, occurs in the three energy-conversion layers below the antireflection layer. The first of these three layers necessary for energy conversion in a solar cell is the top junction layer in Figure 76. The next layer in the structure

Energy-conversion layers

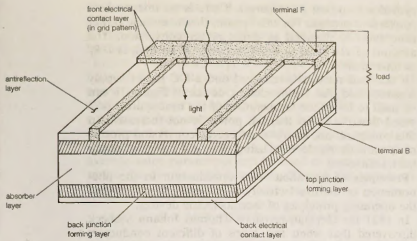

Figure 76: *A commonly used solar-cell structure.* In many such cells, the absorber layer and the back junction layer are both made of the same material.

is the core of the device; this is the absorber layer. The last of the energy-conversion layers is the back junction layer.

As may be seen from Figure 76, there are two additional layers that must be present in a solar cell. These are the electrical contact layers. There must obviously be two such layers to allow electric current to flow out of and into the cell. The electrical contact layer on the face of the cell where light enters is generally present in some grid pattern and is composed of a good conductor such as a metal. The grid pattern does not cover the entire face of the cell since grid materials, though good electrical conductors, are generally not transparent to light. Hence, the grid pattern must be widely spaced to allow light to enter the solar cell but not to the extent that the electrical contact layer will have difficulty collecting the current produced by the cell. The back electrical contact layer has no such diametrically opposed restrictions. It need simply function as an electrical contact and thus covers the entire back surface of the cell structure. Because the back layer must be a very good electrical conductor, it is always made of metal.

It is a fundamental fact of nature that, whenever different materials are placed in contact, an electric field exists at the interface, or junction, between these materials. The role of the junction layers in Figure 76 is to establish this electric field. The field created in the solar cell by the different junction-forming materials is termed the built-in electric field. An electric field is needed in a solar cell because it exerts a force on electrons. If electrons are not attached to specific atoms but are free to roam about in a material, they always will move in a direction dictated by the electric field. This movement constitutes an electric current.

Built-in electric field

The electric field set up by the junction-forming layers of the solar cell causes a current to flow when there are free electrons present in the top junction-forming layer, the absorber layer, and the back junction-forming layer. When light falls on the cell, free electrons occur as a result of the interaction of the light with the absorber layer. The special attribute of this cell layer is that it absorbs light by changing the energy and state (or condition) of some of the electrons in the material. When light is absorbed in the materials, the energy of an electron increases from the so-called ground state energy to an excited energy state. In the excited state, electrons are no longer associated with specific atoms in the absorber, but they are, instead, free to move.

In summary, the absorption of light in the absorber material of a solar cell results in energetic, free electrons that move in the direction forced on them by the built-in electric field. These energetic electrons of the induced current are then collected by the electrical contact layers for use in an external circuit where they can do useful work.

Since most of the energy in sunlight or indoor light is in visible light, a solar-cell absorber should be a strong absorber of electromagnetic radiation in that range of wavelengths. Materials that absorb the visible light of sunlight or of indoor light by producing excited free electrons belong to a class of substances known as semiconductor materials. Semiconductors can absorb all incident visible light in thicknesses of about one-hundredth of a centimetre or less; consequently, the thickness of a solar cell can be of this size. Examples of semiconductor materials employed in solar cells include silicon, gallium arsenide, indium phosphide, and copper indium selenide.

The materials in a solar cell used for the junction-forming layers need only be dissimilar, and, to carry the electric current, they must be conductors. The two junction-forming layers may be different semiconductors or they may be a metal and a semiconductor. Thus, the materials used to construct the various layers of solar cells are essentially the same materials used to produce the diodes and transistors of solid-state electronics and microelectronics (see also ELECTRONICS: *Optoelectronic devices*). Solar cells and microelectronic devices share the same basic technology. In solar-cell fabrication, however, one seeks to construct a large-area device because the power produced is proportional to the illuminated area. In microelectronics the goal is of course to construct devices of very small area to increase the number of circuit components on a single tiny semiconductor chip.

The photovoltaic effect that causes the direct energy conversion in a solar cell is summarized in the schematic of Figure 77. An analogy between an electron in the solar cell and a child at a slide is also presented in this figure. As shown, initially both the electron and the child are in their respective ground states. Next the electron is lifted up to its excited state by consuming energy in the incoming light, just as the child is lifted up to an excited state at the top of the slide by consuming chemical energy stored in his body. In both cases, there is now energy available in the excited state that can be expended. The excited electron is free and moves to the external circuit due to the built-in electric field. It is in this external circuit that the electron will dissipate its excess energy in some device, which in general can be termed a load. The external load is shown here as a simple resistor, but it can be any of a myriad of electrical or electronic devices ranging from motors to radios. Correspondingly, the child moves to the slide because of his desire for excitement. It is on the slide that the child dissipates his excess energy. Finally, when the excess energy is expended, both the electron and the child are back in the ground state where they can, of course, begin the whole process over again. As can be seen from the figure, the motion of the electron, like that of the child, is in one direction. In short, a solar cell produces a direct electric current—namely, one that flows constantly in only a single direction.

Photovoltaic effect

The photovoltaic process bears certain similarities to photosynthesis in plants by which the energy in light is converted into chemical energy. Since solar cells obviously cannot produce electric power in the dark, part of the energy they develop under light is stored, in many applications, for use when light is not available. One common means of storing this electrical energy is to charge chemical

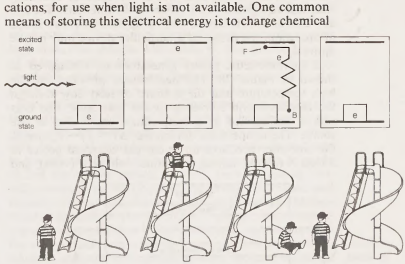

Figure 77: *Representation of an electron in a solar cell.* The electron is shown interacting with light and subsequently dissipating the excess energy it receives from the light by doing work in an external circuit. The electric current flows in and out of the cell through terminals B and F (as represented in Figure 76). The sequence of events involved is analogous to a child playing on a slide (see text).

storage batteries. This sequence of converting the energy in light into the energy of excited electrons and then into stored chemical energy is strikingly similar to the process of photosynthesis.

Development of solar cells. The development of solar-cell technology stems from the work of the French physicist Antoine-César Becquerel in 1839. Becquerel discovered the photovoltaic effect while experimenting with a solid electrode in an electrolyte solution; he observed that voltage developed when light fell upon the electrode. About 50 years later, Charles Fritts constructed the first true solar cells using junctions formed by coating the semiconductor selenium with an ultrathin, nearly transparent layer of gold. Fritts's devices were very inefficient converters of energy; they transformed less than 1 percent of the absorbed light energy into electrical energy. Though inefficient by today's standards, these early solar cells fostered among some a vision of abundant, clean power. In 1891 R. Appleyard wrote of "the blessed vision of the Sun, no longer pouring his energies unrequited into space, but by means of photo-electric cells . . . , these powers gathered into electrical storehouses to the total extinction of steam engines, and the utter repression of smoke."

By 1927 another metal–semiconductor-junction solar cell, in this case made of copper and the semiconductor copper oxide, had been demonstrated. By the 1930s both the selenium cell and the copper oxide cell were being employed in light-sensitive devices, such as photometers, for use in photography. These early solar cells, however, still had energy-conversion efficiencies of less than 1 percent.

First silicon solar cell

This impasse was finally overcome with the development of the silicon solar cell by Russell Ohl in 1941. Thirteen years later three other American researchers, G.L. Pearson, Daryl Chapin, and Calvin Fuller, demonstrated a silicon solar cell capable of a 6-percent energy-conversion efficiency when used in direct sunlight. By the late 1980s silicon cells, as well as those made of gallium arsenide, with efficiencies of more than 20 percent had been fabricated. In 1989 a concentrator solar cell, a type of device in which sunlight is concentrated onto the cell surface by means of lenses, achieved an efficiency of 37 percent due to the increased intensity of the collected energy. In general, solar cells of widely varying efficiencies and cost are now available. (S.J.F./R.T.F.)

THERMOELECTRIC POWER GENERATORS

General characteristics. A unique aspect of thermoelectric energy conversion is that the conversion direction is reversible. This distinguishes thermoelectric energy converters from many other energy conversion systems. Electrical input power can be directly converted to pumped thermal power for the purpose of either refrigeration or heating. Conversely, thermal input power can be converted directly to electrical power for lighting, operating electrical equipment, and other work functions. Though any thermoelectric device can be applied in either mode of operation, the design of a particular device may not be optimal.

Capability for reversible energy conversion

All thermoelectric power generators are configured as shown in Figure 78. The heat source provides for the high temperature and the amount of heat flow through the thermoelectric converter to the heat sink. The heat sink is maintained at a temperature below that of the source. The temperature differential, $\Delta T = T_1 - T_0$, across the converter produces direct-current electrical power to a load R (ohms), having a terminal voltage V (volts), and provides a current I (amperes). There is no intermediate conversion process. For this reason, thermoelectric power generation is classified as direct power conversion. The amount of electrical power generated, W (watts), is I^2R_L or alternately VI.

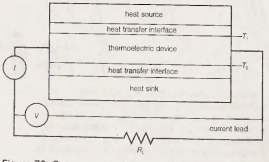

Figure 78: Components of a thermoelectric generator.

If the load resistor is removed and a DC power supply is substituted, the thermoelectric device of Figure 78 can be used to lower the temperature of the heat source, provided that the input thermal power is not increased. In this configuration, the reversed energy-conversion process of thermoelectric devices, using electrical power to pump heat, is invoked.

Principles of operation. An introduction to the phenomenon of thermoelectricity is necessary to understand the operating principles of thermoelectric devices.

In 1821 the German physicist Thomas Johann Seebeck discovered that when two strips of different conductors (metals, semimetals, or semiconductors—the distinction was not understood at that time) were joined together at their ends and separated along their length, a magnetic field developed around the two legs, provided however that a temperature difference existed between the two junctions. He published his observations the following year, and the phenomenon came to be known as the Seebeck effect. The significance of his discovery notwithstanding, Seebeck did not correctly identify the cause of the magnetic field. The magnetic field results from an equal but opposite electric current in the leg of each metal strip caused by a thermally generated electric potential difference between the junctions. If one junction is broken but the temperature differential is maintained, current no longer flows in the legs but a voltage can be measured. This generated voltage, V, is the Seebeck voltage and is related to the difference in temperature, ΔT, between the heated junction and opened junction by a proportionality factor, α, called the Seebeck coefficient, or $V = \alpha\Delta T$. The value for α is dependent on the types of material at the junction.

Seebeck effect

In 1834 the French physicist and watchmaker Jean-Charles-Athanase Peltier observed that if a current is passed through a single junction of the type described above, the amount of measured heat generated is not consistent with that which would be predicted from Joule heating (see below) alone. This observation is called the Peltier effect. As in Seebeck's case, Peltier failed to define the cause of the anomaly. He did not identify that heat was absorbed or evolved at the junction depending on the direction of current. He also did not recognize the reversible nature of this thermoelectric phenomenon and associate his discovery with Seebeck's.

Peltier effect

It was not until 1855 that William Thomson (later Lord Kelvin) drew the connection between the Seebeck and Peltier effects and made a significant contribution to the understanding of thermoelectric phenomena. The Peltier heat, Q_π, was shown to be proportional to the applied junction current, I, through the relationship $Q_\pi = \pi I$, where π is the Peltier coefficient. Thomson showed through thermodynamic analysis that $\pi = \alpha T$, where T is the absolute temperature of the junction. The Thomson effect, theoretically predicted by Thomson on the basis of thermodynamic considerations, showed that heat is absorbed or evolved, Q_τ, along the length of a material rod whose ends are at different temperatures. Q_τ was shown to be proportional to the flow of current, I, and the temperature gradient along the rod. The proportionality factor, τ, is known as the Thomson coefficient.

Thomson effect

All thermoelectric phenomena are described by these three effects. Analysis of a thermoelectric device is, however, adequately performed using only one of the thermoelectric parameters, the Seebeck coefficient, α. The reason is that the Thomson effect is small, and so it is generally neglected. The Peltier coefficient, on the other hand, is related to α through the operating condition of the junction temperature.

Two nonthermoelectric quantities must also be identified before a thermoelectric device can be appropriately described. They are Joule heating (the production of heat in a conductor when a current flows through it, as in the case of filaments of an electric kitchen range or toaster) and thermal conduction (the transfer of heat due to tem-

perature differences between adjacent parts of a body). Although a thermoelectric device is made up of many *p*-type and *n*-type semiconductor legs, its behaviour can be discussed using only one couple.

Figure 79 shows a *p*-type and *n*-type semiconductor leg coupled to a heat source, heat sink, and an electrical power consuming load. (Other couples can be connected electrically in series and thermally in parallel.) The leg geometry affects operation. The leg length is L, and the base area, a, is w^2. Under the condition that *p*- and *n*-type semiconductors are similar in their measured properties, average value parameters can be used to analytically describe the couple. The heat flow through the couple at T_1 is given by

$$H = 2\alpha I T - I^2\rho\left(\frac{L}{a}\right) + 2\kappa\left(\frac{a}{L}\right)\Delta T,$$

where temperature is in kelvins, ρ is the electrical resistivity in ohms-centimetre, κ is the thermal conductivity in watts per centimetre kelvin, α is microvolts per kelvin, and L/a is in centimetres^{-1}. In this equation, the first term results from the reversible Peltier effect that generates heat at the top junction. The second term reflects loss due to irreversible Joule heating (one half of the total amount generated). The last term is the irreversible heat loss due to thermal conductivity in each leg.

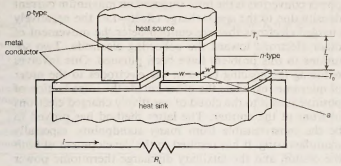

Figure 79: Single couple of a thermoelectric generator.

In a thermoelectric power generator, a temperature differential between the upper and lower surfaces of two legs of the device results in power being generated. If a power consuming load is not attached to the generator (open-circuited), the applied heat source (H) results in a temperature differential (ΔT) of some value dictated only by the thermal conductivity of the *p*- and *n*-type semiconductor legs. Since no current would flow in the thermoelectric device, no power would be generated. (The first and second terms of the above equation would be zero.) Because of the Seebeck effect, however, a voltage would be present at the output terminals, just like in an unconnected battery. When a load is attached, current will flow through the load. The Seebeck voltage $V_s = \alpha\Delta T$ is divided between two terms: the internal device voltage drop IR_{int} due to internal resistance $R_{int} = 2\rho(L/a)$ (for the couple), and the external voltage drop IR_L. It is the Seebeck voltage and these two resistances that dictate the flow of current (and the generated output electrical power) given by

$$I = \frac{2\alpha\Delta T}{(R_{int} + R_L)}.$$

This same current pumps heat within the thermoelectric device due to the Peltier effect, which in turn results in a lowering of the initial temperature differential when the current is zero. Part of the heat energy, H, through the Seebeck generated current, is converted to Joule heating within the legs of the thermoelectric device. The efficiency, η, for a power generator is the output power, I^2R_L, divided by H. It can be shown that

Thermal efficiency

$$\varepsilon\ \max = \left(\frac{T_1 - T_0}{T_1}\right)\left(\frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_0}{T_1}}\right),$$

where the first term is the Carnot efficiency (see *Transformation of energy* above). The second term contains T, which is the average temperature of the leg. The Z is the figure of merit of the semiconductor legs; it represents a "quality factor" of the material to perform as thermoelectric device (it is 3×10^{-3} per kelvin at 300 K), given by

$$Z = \frac{\alpha^2}{\kappa\rho}.$$

For material quality to improve (*i.e.*, larger Z), it is generally agreed that the thermal conductivity (κ) and electrical resistivity (ρ) of semiconductor materials must decrease. This has been the principal limiting factor toward higher conversion efficiency in thermoelectric power generation, which in turn has limited the use of thermoelectric devices. A new effort in materials research is required to obtain materials that can improve the overall efficiency of thermoelectric devices.

Major types of thermoelectric generators. Thermoelectric power generators vary in geometry, depending on the type of heat source and heat sink, power requirement, and intended use. In general, many units require a power conditioner to convert the generator output to a usable voltage value. Although the Soviet army used these devices to power portable communications transmitters during World War II, modern power generators are based on the substantial improvements made in semiconductor materials and electrical contacts between 1955 and 1965, as well as on engineering improvements achieved up to the present.

Fossil-fuel generators. Units have been constructed to use natural gas, propane, butane, kerosene, jet fuels, and wood, to name but a few heat sources. A 500-watt multifuel, maintenance-free tactical power generator for advance area application has been developed for the U.S. Army. Commercial units are in the 10- to 100-watt output power range for use in remote areas. Applications for these units include navigational aids, data collection systems and communications systems, and cathodic protection, which prevents electrolysis from corroding metallic pipelines and marine structures.

Solar-source generators. Early attempts to construct solar thermoelectric generators for orbiting spacecraft failed because of low efficiency and higher unit weight compared to silicon solar cells. They have, however, been used with some success to power small irrigation pumps in remote areas and underdeveloped regions of the world where fuel sources are unreliable. In addition, a group of U.S. researchers have described an experimental system capable of using warm surface ocean water as the heat source and cooler deep ocean water as the heat sink for large power generation. Economics favouring this system are based on it being so reliable that there is minimal maintenance cost. Still another system design features both heat pumping and power generation for thermal control of orbiting spacecraft. Utilizing solar heat from the Sun-oriented side of the spacecraft, thermoelectric devices generate electrical power. This power is used to supply current to other thermoelectric devices in dark areas of the spacecraft to reject heat from the vehicle. Operating in this mode, the use of thermoelectric devices, with their reversible function capability, decreases the amount of power required by the spacecraft to increase overall heat expulsion.

Nuclear-fueled generators. Thermoelectric generators that use radioisotopes as fuel derive a high-temperature heat source by the self-absorption of emitted decay products. Because thermoelectric devices are relatively immune to nuclear radiation and because the source can be made to last for a long period of time, such generators provide a unique source of power for many unattended and remote applications. For example, radioisotope thermoelectric generators provide electric power for nonorbiting as well as Earth-orbiting spacecraft, instrumentation for deep-ocean data collection and surface monitoring, warning and communications systems, isolated terrestrial weather monitoring stations, and certain medical applications. A low-power radioisotope thermoelectric generator was developed as early as 1970 and used to power cardiac pacemakers. The power range of radioisotope thermoelectric generators is between 10^{-6} and 10^{2} watts.

Applications of radioisotope thermoelectric generators

Development of thermoelectric power generators. The

first application of a thermoelectric generator was in all likelihood Peltier's use of the Seebeck effect (see above) to generate a small amount of power required to pump heat in his junction experiments. An understanding of the principle involved in this phenomenon led to the use of dissimilar metal wires for measuring temperature—namely, the thermocouple. From this evolved the use of multiple but alternating dissimilar metallic wires in a thermopile with which to measure optical radiation.

As the need for electric power became increasingly more important between 1885 and 1910, investigators began studying thermoelectricity systematically. By 1910 E. Altenkirch, a German scientist, satisfactorily calculated the efficiency of thermoelectric generators and delineated the parameters of the materials needed to build practical devices. Unfortunately metallic conductors were the only materials available at the time, rendering it unfeasible to build thermoelectric generators with an efficiency of more than 0.6 percent.

During the late 1920s, Soviet researchers actively pursued theoretical and experimental work on thermoelectricity because of the need for electric power in remote yet habitable areas of their vast country. By 1940 a unit with a conversion efficiency of 4 percent had been developed using semiconductors. It was quickly realized that semiconductor materials were best suited for thermoelectric application. By the early 1950s, interest in thermoelectric power generation was on the rise in certain highly industrialized nations, most notably the United States. Scientific projects being undertaken by these countries in isolated, uninhabited areas necessitated power sources for data collection and communications systems. Yet, in spite of the increased research and developmental activity, gains in thermoelectric power-generating efficiency were relatively small. An efficiency capability of not much more than 10 percent had been attained as of the late 1980s. Better thermoelectric materials are required to go much beyond this performance level. Still, some varieties of thermoelectric generators have proved to be of considerable practical import. Those fueled by radioisotopes are the most versatile, reliable, and generally used power source for isolated or remote sites. (J.W.H.)

Adoption of semiconductors

THERMIONIC POWER CONVERTERS

General characteristics. A thermionic power converter—also variously called thermionic generator, thermionic power generator, or thermoelectric engine—is a device in which heat energy is directly converted into electrical energy. It has two electrodes. One of these is raised to a sufficiently high temperature to become a thermionic electron emitter and can be dubbed the "hot plate." The other electrode, called a collector because it receives the emitted electrons, is operated at a significantly lower temperature. The space between the electrodes is normally filled with a vapour or gas at low pressure (on the order of 1.333×10^2 pascals). The thermal energy may be supplied by chemical, solar, or nuclear sources.

Primary components

Principles of operation. The emission of electrons from the hot plate is analogous to the liberation of steam particles when water is heated. The flow of electrons may be completed by interconnecting the two electrodes by an external load, shown by a resistor R_L in Figure 80. Part of the thermal energy that is supplied to liberate the electrons ("boil them off") is converted directly into electrical energy.

A thermionic power converter can be viewed in several different ways. It can, for example, be examined in terms of thermodynamics as a heat engine that utilizes an electron-rich gas as its working fluid. A thermionic converter also may be thought of as a thermoelectric device—a thermocouple in which one of the conductors has been replaced by either a plasma or a vacuum (*i.e.*, an evacuated space). It can even be regarded in terms of electronics as a diode that converts heat to electrical energy via thermionic emission. No matter how thermionic converters are conceived of or labeled, however, they all work due to the discharge of electrons from heated conducting materials. The following discussion treats devices of this sort as heat engines.

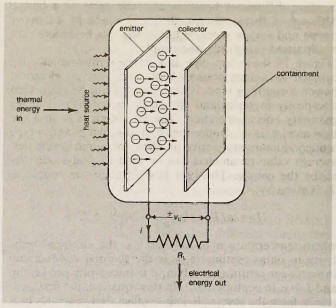

Figure 80: Schematic of a basic thermionic converter.
From E.M. Walsh, *Energy Conversion*, copyright © 1967 by the Ronald Press Company, reprinted by permission of John Wiley & Sons, Inc.

The major problem in developing large-scale thermionic power converters is the limit imposed on maximum current density due to the space-charge effect—*i.e.*, the negatively charged electrons that are emitted deter the movement of other electrons toward the collecting electrode. Two solutions to this problem have been pursued. One involves reducing the spacing between the electrodes to the order of micrometres, while the other entails the introduction of positive ions into the cloud of negatively charged electrons in front of the emitter. The latter method has proved to be the most feasible from many standpoints, especially manufacturing. It has resulted in the development of both the cesium and the auxiliary discharge thermionic power converters.

Minimizing space-charge effect

Thermionic emission. The emission of electrons is fundamental to thermionic power conversion. The mechanism for the escape of an electron is shown in Figure 81. The actual effect of a negatively charged electron (Figure 81A) may be represented equivalently by a positively charged electron located in a mirror-image arrangement (Figure 81B). This model permits the escape force to be determined from a fundamental law of physics, the inverse square law. That force is given by

$$\frac{e^2}{16\pi\varepsilon_0 x^2},$$

where e is electronic charge (coulombs) and ε_0 is permittivity of free space. The energy required to overcome this force—to cause the electron to escape—is called the work function φ. Each material has a unique value, as shown in Table 4, at common emitter temperatures above 2,000 K. (Collectors normally operate around 1,000 K.) The other parameter tabulated, R, is material-dependent, although the theoretical derivation of the governing equation fixes

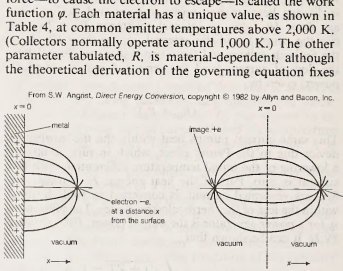

Figure 81: *Mechanism for electron escape in thermionic power conversion.*
(A) The electric field lines for an electron near the surface of a metal. (B) Electric field lines for an image charge +e and an electron at equal distances on either side of $x = 0$. The field for x greater than zero is identical with the field A (see text).

its value as a universal constant $R = 1.2 \times 10^{-6}$ amperes per square metre kelvin squared (amp/m^2-K^2).

The rate at which electrons are liberated from the surface of the emitter is given by the Richardson–Dushman electron current density equation; *i.e.*,

Richardson–Dushman equation

$$J_0 = RT^2 \exp\left(-\frac{e\varphi}{kT}\right),$$

where T is absolute temperature (K) and k is Boltzmann's gas constant for one molecule (ergs per kelvin). This equation for emission current is named for Owen Willans Richardson and Saul Dushman, who did pioneering work on the phenomenon. The rate of emission increases rapidly with temperature and decreases exponentially with the work function. It is always desirable to operate a thermionic converter at a high temperature as well as to be selective in choosing its electrode material.

When electrons escape the emitter surface, they gain energy equal to the work function with some excess kinetic energy. Upon striking the collector, their kinetic energy is used to "absorb" the electrons into the surface. This absorbed energy must be rejected as heat from the collector or force the electrons through the external load, thereby giving the desired electrical energy conversion.

Table 4: Thermionic Emission Properties of Certain Materials

material	φ (volts)	R (amp/m^2-K^2) $\times 10^{-6}$
Cesium	1.89	0.5
Molybdenum	4.2	0.55
Nickel	4.61	0.3
Platinum	5.32	0.32
Tungsten	4.52	0.6
Tungsten + cesium	1.5	0.03
Tungsten + barium	1.6	0.015
Tungsten + thorium	2.7	0.04
Barium oxide	1.5	0.001
Strontium oxide	2.2	1.0

Major types of thermionic converters. *Vacuum converters.* This type of thermionic device has a vacuum gap between its electrodes. Because of the small spacing required between the emitter and collector to counteract the space charge, the vacuum converter has had only limited practical application; however, it has given rise to other configurations of greater utility. They are briefly described below.

Gas-filled converters. These devices are designed in such a way that positively charged ions are continuously generated and mixed with negatively charged electrons in front of the emitter to neutralize the electrostatic field. Because of this, a liberated electron has no electrostatic resistance in passing from the emitter to the collector. Figure 82 shows schematically the operation of a cesium-filled converter. Cesium is used in the most efficient converters because of its low ionization potential (3.87 electron volts). Potassium, rubidium, and various other metals produce similar results. The arrival rate of neutral cesium atoms is dependent on the gas pressure of cesium and its reservoir temperature. For efficient production of ions, the emitter temperature should be approximately 3.6 times the reservoir temperature.

Auxiliary discharge converters. Such thermionic generators operate at lower temperatures (say, 1,500 K), permitting the use of a fossil-fuel heat source. Ions are produced by applying voltage to a third electrode, shown schematically as auxiliary anodes in Figure 83. The gas between the electrodes in this system is inert (e.g., neon, argon, or xenon). The principal advantage of the auxiliary discharge converter—so called because of its spark plug-type configuration—is that conventional fossil fuels are adequate for the heat source. The disadvantage is the complexity of the discharge system.

Fossil fuels as heat source

Because thermionic converters are tolerant of high accelerations, have no moving parts, and exhibit a relatively high power-to-weight ratio, they are well suited for applications in spacecraft. Since they function best at high temperatures, they may be used as topping devices (*i.e.*, power boosters) on conventional power plants. Their efficiencies make them suitable power sources for remote or hostile environments (*e.g.*, under water) or for use in low-power radio transmitters.

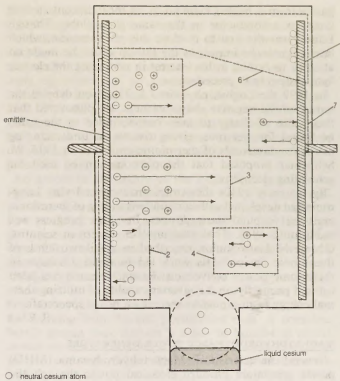

Figure 82: *The various processes in a gas-filled converter.* They occur in the following sequence: (1) evaporation of liquid cesium, (2) arrival of cesium atoms at emitter and departure as ions, (3) neutralization of space charge, (4) energy sharing of ions with atoms, (5) formation of an ion space-charge sheath, (6) reduction of work function due to cesium deposition, and (7) cesium ion recombination at the collector surface.

From S.W. Angrist, *Direct Energy Conversion*, copyright © 1982 by Allyn and Bacon, Inc.

Development of thermionic devices. As early as the mid-18th century, Charles François de Cisternay Du Fay, a French chemist, noted that electricity may be conducted in the gaseous matter—that is to say, plasma—adjacent to a red-hot body. In 1853 the French physicist Alexandre-Edmond Becquerel reported that only a few volts were required to drive electric current through air between high-temperature platinum electrodes. From 1882 to 1889 Julius Elster and Hans Geitel of Germany perfected a sealed device containing two electrodes, one of which could be heated while the other one was cooled. They discovered that, at fairly low temperatures, electric current flows with little resistance if the hot electrode is positively charged. At moderately higher temperatures, current flows readily in either direction. At even higher temperatures, however, electric charges from the negative electrode flow with the greatest ease.

In the 1880s the American inventor Thomas A. Edison applied for a patent pertaining to thermionic emission in a vacuum. In his patent request, he explained that a current

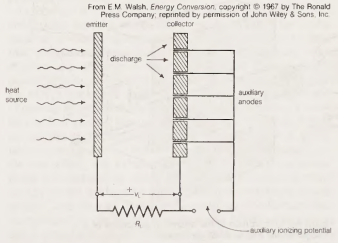

Figure 83: Auxiliary discharge converter.

Edison effect

passes from a heated filament of an incandescent electric lamp to a conductor in the same glass globe. Though Edison was the first to disclose this phenomenon, which later came to be known as the Edison effect, he made no attempt to exploit it; his interest in perfecting the electric light system took precedence.

In 1899 the English physicist J.J. Thomson defined the nature of the negative charge carriers. He discovered that their ratio of charge to mass corresponded to the value he found for electrons, giving rise to an understanding of the fundamentals of thermionic emission. In 1915 W. Schlichter proposed that the phenomenon be used for generating electricity.

By the early 1930s the American chemist Irving Langmuir had developed sufficient understanding of thermionic emission to build basic devices, but little progress was made until 1956. That year another American scientist, George N. Hatsopoulos, described in detail two kinds of thermionic devices. His work led to rapid advances in thermionic power conversion. Recent research has been centred primarily on a converter capable of utilizing thermal energy from a nuclear reactor on board spacecraft.

(L.E.Si.)

MAGNETOHYDRODYNAMIC POWER GENERATORS

General characteristics. Magnetohydrodynamic (MHD) power generators produce electrical power through the interaction of a flowing, electrically conducting gas (or other fluid) and a magnetic field. Various countries—including Japan, China, Poland, Russia, and the United States—have undertaken active developmental programs, since MHD power plants offer the potential for large-scale electrical power generation at reasonable cost with comparatively little detrimental impact on the environment. Generators of the MHD type are also attractive for the production of large electrical power pulses, and their first practical application has been for this kind of service (see below).

The underlying principle of MHD power generation is elegantly simple. An electrically conducting fluid is driven by a primary energy source (*e.g.*, combustion of coal or a gas) through a magnetic field, resulting in the establishment of an electromotive force within the conductor in accordance with the principle established by Faraday (see above). Furthermore, if the conductor is an electrically conducting gas, it will expand, and so the MHD system constitutes a heat engine involving an expansion from high to low pressure in a manner similar to that of a gas turbine. The MHD system, however, involves a volume interaction between a gas and the magnetic field through which it is passing (see below), whereas the gas turbine operates through the gas interaction with the surfaces of a rotating blade system. It is, in effect, a system that depends on volume rather than surface interaction.

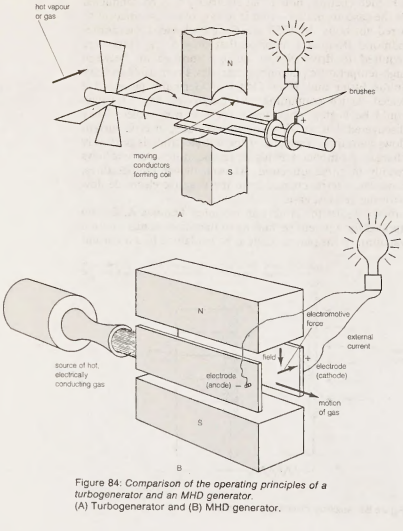

Figure 84: *Comparison of the operating principles of a turbogenerator and an MHD generator.*
(A) Turbogenerator and (B) MHD generator.

The MHD generator as an electromagnetic turbine

The MHD generator can properly be viewed as an electromagnetic turbine because its output is obtained from the conducting gas–magnetic field interaction directly in electrical form rather than in mechanical form, as in the case of a gas (or steam) turbine. This is illustrated in Figure 84, which compares a conventional turbogenerator with an MHD system. Other types of MHD turbines are possible and will be mentioned below. Here, attention is concentrated on the electrically conducting gas type, which has been the focus of most research and developmental work.

Electrical conduction in gases occurs when electrons are available to be organized into an electric current in response to an applied or induced electric field. The electrons may be either injected or generated internally, and, because of the electrostatic forces involved, they require the presence of corresponding positive charge from ions to maintain electrical neutrality. An electrically conducting gas consists in general of electrons, ions to balance the electric charge, and neutral atoms or molecules. Such a gas is termed a plasma.

In MHD generators, electrons for supporting the flow of current can be obtained in either of two ways: by heating the gas to a sufficiently high temperature to yield electrons through ionization or by the induction of a sufficiently strong electric field in a manner similar to that in gas-discharge devices. These methods are referred to as thermal ionization and nonequilibrium ionization, respectively. In either case, the mechanism of energy transfer from the flowing fluid to the electrical output can be thought of as a coupling of the electron-comprised gas to the ions through electromagnetic forces; the ions in turn are embedded in the background of atomic or molecular gas and lack mobility by virtue of their being coupled to the molecules or ions through collision processes described by kinetic behaviour.

Interest in MHD-power generation was originally stimulated by the observation that the interaction of a plasma with a magnetic field could occur at much higher temperatures than were possible in a system consisting of a rotating mechanical system. The limiting performance from the point of view of efficiency in heat engines is established by the Carnot efficiency, obtained from the difference between the absolute hot source temperature, T_1, and the cold sink temperature, T_0, divided by T_1. For example, when the source temperature is 2,810 K and the sink temperature is that of the environment (say, 294 K), the Carnot efficiency is slightly less than 90 percent. Allowing for the inefficiencies introduced by finite heat transfer rates and component inefficiencies in real heat engines, a system employing an MHD generator offers the potential of an ultimate efficiency in the range 60 to 65 percent. This is to be compared with 35 to 36 percent achieved by a modern coal-fired, steam-turbine plant with scrubbers (devices that absorb sulfur dioxide from exhaust gases); 40 percent with a natural gas-fired, steam-turbine plant; and about 46 percent projected for gas-fired, combined gas–steam turbine installations. The implications of this efficiency improvement are an enhanced utilization of primary fuel resources due to higher thermodynamic efficiency and a lower emission of environmental pollutants. (The environmental advantages are discussed in *Major types of MHD systems* below.)

Comparatively high conversion efficiency

Principles of operation. As in the case of all electrical machines, the power output of MHD generators for every cubic metre of conductor depends directly on its conductivity, the square of the velocity at which the conductor

moves, and the square of the magnetic field through which it is passing. For MHD generators to operate competitively, the electrical conductivity of the plasma must be adequate to achieve good performance and reasonable physical dimensions in the temperature range of about 1,800 K and upward—*i.e.*, temperatures at which the turbine blades of a gas-turbine power system would no longer be able to operate. Analysis shows, and experience confirms, that adequate conductivity results if a small amount of additive, typically around 1 percent by mass, is injected into the working gas of the MHD system. This additive is in the form of readily ionizable material such as potassium carbonate and is referred to as the "seed." It is the principal source of electrons (and ions) that render the gas electrically conducting and thereby enable direct conversion to occur.

Addition of a seed material

The hot gas, at a pressure of several megapascals, has seed material added and is accelerated by a nozzle to a speed usually greater than that of sound (*i.e.*, to supersonic conditions). As shown in Figure 85, it then enters a containment structure known as the channel, or duct, across which a powerful magnetic field is applied. In accordance with the Faraday induction principle, an electromotive force acting in a direction perpendicular to the flow and field is set up and, to enable this to provide a current to an external circuit, the walls parallel to the magnetic field serve as electrodes. Because the electromagnetic force is induced in the gas, the positive electrode is the cathode, or electron emitter, and the negative electrode is the anode, or collector (Figure 85). The remaining two walls of the channel are insulators that confine the resultant voltage. Depending on the heat source and magnetic field strength, power densities of 10 to 500 megawatts per cubic centimetre in the duct can be obtained. A magnetic field in the range 4.5 to 6 teslas is required to achieve these values, and this is most readily obtained by using a superconducting magnet.

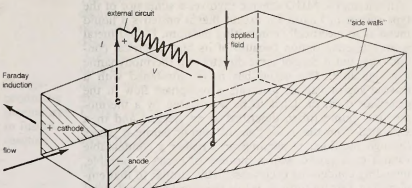

Figure 85: *Simple MHD generator.*
The load current is represented by *I* and the voltage by *V* (see text).

A complicating feature of a plasma MHD generator is the occurrence of a pronounced Hall effect, which results from the behaviour of electrons in the presence of both magnetic and electric fields. Electrons are accelerated in the direction of an electric field but follow a circular path around a magnetic field line (cyclotron behaviour). When these two actions are combined and the collision processes taken into account, the effect (named after its discoverer, the American physicist Edwin H. Hall) is for the electric current to flow at an angle with respect to the electric field, producing an additional field along the axis of the MHD duct. This field, called the Hall field, causes an axial current (Hall current) to flow if the electrodes are continuous, as in Figure 85. This in turn requires that either the electrode walls be constructed to support the Hall field or that the Hall field itself be used as the output to drive current through the electric circuit external to the MHD system.

A number of generator configurations can be used to achieve this objective. The principal ones are briefly described here. In the so-called Faraday generator (Figure 86A), the electrode walls are segmented to support the axial potential, and the power is taken out in a series of loads. The Hall generator (Figure 86B) maximizes the Hall output by short-circuiting the Faraday terminals and connecting a simple load between the ends of the duct. Consideration of the potentials at different points in the duct have led to the conclusion that an equipotential runs diagonally (across the insulator walls) and that, accordingly, electrodes may be connected along such a potential to achieve the diagonal configuration shown in Figure 86C. This diagonal generator may be thought of as a Faraday type in which the individual electrode pairs have been connected in series in a manner that does not violate the potential required for correct operation of the duct yet permits a single load to be used.

MHD generator configurations

An attractive alternative to the linear Hall generator in Figure 86B is the disk generator in which a radial output flow occurs and the short-circuited Faraday currents flow in closed circular paths (Figure 86D). The Hall output appears between the centre and the periphery of the disk. This disk generator is particularly attractive when nonequilibrium ionization is employed.

Major types of MHD systems. The type of ionization employed by an MHD power generator depends on the heat source selected and the method used to couple it to the working fluid. Several possibilities exist. A complete MHD system may include a solid- or liquid-fuel rocket motor (see *Rockets* above), seed injector, nozzle, duct, and magnet and may utilize thermal ionization in the combustion products that make up the working fluid. MHD generators currently in service are of this type. They are compact systems capable of providing very large amounts of power. Natural gas, oil, and coal also are excellent potential fuels for MHD systems and were in fact the first to be proposed and considered. With the addition of oxygen or compressed preheated air or both, these fossil fuels yield combustion products that readily reach the temperatures required for thermal ionization.

Possible fuel sources

Although conventional nuclear fission reactors of the light-water type operate at temperatures too low for MHD applications, nuclear heat sources represent still another option for MHD systems. If a nuclear heat source were employed, hydrogen or a noble gas such as argon or helium would be appropriate for the working fluid, and nonequilibrium ionization could be used. A possible candidate for this kind of heat source is the NERVA (nuclear energy for rocket vehicle application) high-temperature fission reactor, originally designed for space propulsion. While the ultimate form of fusion reactor has yet to be determined, it should be feasible to devise a scheme for coupling an MHD generator to a nuclear source of this type (see below). Solar concentrators also can in theory achieve the temperatures required for MHD operation, and there have been several proposals for exploiting solar radiation to provide the necessary thermal energy.

The use of fission and fusion reactors as heat sources for MHD generators is contingent upon the development of suitable high-temperature reactor systems. Similarly, in the case of solar-based MHD, high-temperature collectors for solar thermal systems are required. Since such systems have yet to be constructed, attention has so far been focused on fossil- and chemical-fueled systems, with the primary aim of using MHD technology for central station power generation.

As energy is extracted from an MHD generator, duct conditions become increasingly less favourable for maintenance of electrical conductivity and, in the case of thermal ionization, extraction is essentially completed when the temperature falls to about 2,500 K. A central station power system thus has to be based on a binary cycle, with an MHD generator topping a conventional steam plant. (Topping means that the gas generated by burning a fossil fuel is first passed through the MHD generator and then on to the turbogenerator of the ordinary power plant, which constitutes the bottoming portion of the binary cycle.) In effect, the exhaust gas from the MHD generator feeds the bottoming cycle so that the residual thermal energy in the gas can be used to furnish additional power output and also to preheat the oxidizer for further fuel combustion in the MHD generator. An MHD power plant employing such an arrangement is an open-cycle ("once-through") system.

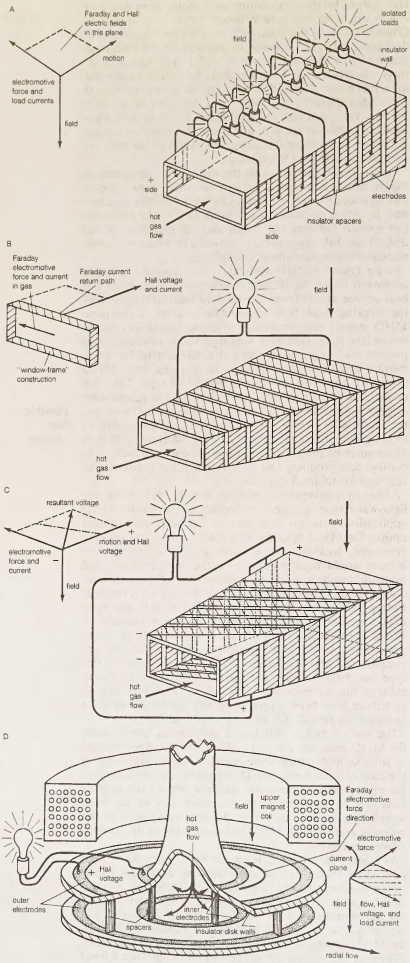

Figure 86: *MHD generator configurations.*
(A) Segmented Faraday generator, (B) Hall generator, (C) diagonal generator with 'window-frame' construction, and (D) disk generator (see text).

The abundance of coal reserves in the United States has favoured the development of coal-fired MHD systems for domestic use. Coal combustion as a source of heat has several advantages. For example, it results in coal slag, which under magnetohydrodynamic conditions is molten and provides a layer that covers all of the insulator and electrode walls. The electrical conductivity of this layer is sufficient to provide conduction between the working gas and the electrode structure but not so high as to cause any significant leakage of electric currents and consequent loss. Indeed, the reduced thermal loss to the walls due to the slag layer more than compensates for any electrical losses arising from its presence.

Environmental benefits of coal-fired MHD power plants

The use of a seed material in conjunction with coal firing offers environmental benefits. When sulfur is present in the coal, the recombination chemistry that occurs in the duct of an MHD generator as the gas proceeds to lower temperatures favours the formation of potassium sulfate and so facilitates the removal of sulfur from high-sulfur coals. This in turn sharply reduces sulfur dioxide emissions. Moreover, the need to recover seed material ensures that a high level of particulate removal is built into an MHD coal-fired plant. Finally, by careful design of the boiler and control of combustion, very low levels of nitrogen oxides can be achieved. From an environmental viewpoint, MHD power systems offer effluent levels impressively lower than those currently established by the Environmental Protection Agency (EPA) in the United States.

The need to provide large pulses of electrical power at remote sites has stimulated the development of pulsed MHD generators. For this application, the MHD system consists basically of a rocket motor, duct, magnet, and connections to electrical load. Similar generators were routinely operated by Soviet scientists as sources for pulse-power electromagnetic sounding apparatuses used in geophysical research; power levels up to 100 megawatts were reported. In this application, the MHD generator provides a power pulse typically of a few seconds' duration to a magnetic or electric dipole located on the surface. The magnetic fields induced in the crust of the Earth are measured, and, through electrical conductivity, properties of the crust are determined.

An alternative MHD scheme involves a generator of the type shown in Figure 85, except that it employs a liquid metal as its electrically conducting medium. Liquid metal is an attractive option because of its high electrical conductivity, but it cannot serve directly as a thermodynamic working fluid. The liquid has to be combined with a driving gas or vapour to create a two-phase flow in the generator duct, or it has to be accelerated by a thermodynamic pump (often described as an ejector) and then separated from the driving gas or vapour before it passes through the duct. Depending on whether a condensable vapour or a gas is used, a number of cycles is possible, including condensing cycles essentially similar to that employed in a steam turbine. While the so-called liquid metal MHD systems offer attractive features from the viewpoint of electrical machine operation, they are limited in temperature by the properties of liquid metals to about 1,250 K. They thus have to compete with various existing energy-conversion systems and with other advanced systems capable of operating in the same temperature range.

The use of MHD generators to provide power for spacecraft for both burst and continuous operations has been considered. While both chemical and nuclear heat sources have been investigated, the latter is the preferred choice for applications such as supplying electric propulsion power for deep-space probes.

Development of MHD power generators. The first recorded MHD investigation was conducted in 1821 by the English chemist Humphry Davy when he showed that an arc could be deflected by a magnetic field. More than a decade later, Faraday sought to demonstrate motional electromagnetic induction in a conductor moving through the magnetic field of the Earth. To this end he set up in January 1832 a rudimentary open-circuit MHD generator, or flow meter, on the Waterloo Bridge across the River Thames. His experiment was unsuccessful, however, owing to the electrodes being electrochemically polarized, an effect not understood at that time.

Early work by Faraday

Faraday soon turned his attention to other aspects of electromagnetic induction, and MHD power generation received little attention until the 1920s and '30s, at which time B. Karlovitz, a Hungarian-born engineer, first pro-

posed a gaseous MHD system of the type described above. In 1938 he and D. Halász set up an experimental MHD facility at the Westinghouse research laboratories and by 1946 had shown that, through seeding the working gas, small amounts of electric power could be extracted. The project was abandoned, however, largely because of a lack of understanding of the conditions required to make the working gas an effective conductor.

First successful MHD power generator

Interest in magnetohydrodynamics grew rapidly during the late 1950s as a result of extensive studies of ionized gases for a number of applications. In 1959 the American engineer Richard J. Rosa operated the first truly successful MHD generator; this device produced about 10 kilowatts of electric power. By 1963 the Avco Research Laboratory, under the direction of the American physicist Arthur R. Kantrowitz, had constructed and operated a 33-megawatt MHD generator, and for many years this remained a record power output. The assumption in the late 1960s that nuclear power would dominate commercial power generation and the failure to find applications for space missions led to a sharp curtailment of MHD research. The energy crisis of the 1970s, however, brought about a revival, with the focus centred on coal-fueled systems in the United States and various other countries. By the late 1980s, development had reached the point where the construction of a complete demonstration system was feasible and, with the environmental advantages resulting from efficient conversion becoming increasingly apparent, the incentive to construct such a system within the next decade gained impetus. (W.D.J.)

FUSION REACTORS

Since the 1930s, scientists have known that the Sun and other stars generate their energy by nuclear fusion. They realized that if fusion energy generation could be replicated in a controlled manner on Earth, it might very well provide a safe, clean, and inexhaustible source of energy. The 1950s saw the beginning of a worldwide research effort to develop a fusion reactor. The substantial accomplishments and prospects of this continuing endeavour are described here.

General characteristics. The energy-producing mechanism in a fusion reactor is the joining together of two light atomic nuclei. When two nuclei fuse, a small amount of mass, m, is converted into a large amount of energy, E. Energy and mass are related through Einstein's relation, $E = mc^2$, by the large conversion factor c^2, where c is the speed of light. The inverse process, conversion of mass to energy by the splitting of a heavy nucleus, is the basis for the fission reactor (see *Nuclear fission reactors* above).

Energy-producing mechanism in fusion reactors

Fusion reactions are inhibited by the electrical repulsive force that acts between two positively charged nuclei. For fusion to occur, the two nuclei must approach each other at high speed to overcome the electrical repulsion and attain a sufficiently small separation (less than one-trillionth of a centimetre) that the short-range strong nuclear force dominates. For the production of useful amounts of energy, a large number of nuclei must undergo fusion; that is to say, a gas of fusing nuclei must be produced. In a gas at extremely high temperature, the average nucleus contains sufficient kinetic energy to undergo fusion. Such a medium can be produced by heating an ordinary gas of neutral atoms beyond the temperature at which electrons are knocked out of the atoms. The result is an ionized gas consisting of free negative electrons and positive nuclei. This gas constitutes a plasma. Most of the matter in the universe is in the plasma state.

The scientific problem of fusion is thus the problem of producing and confining a hot, dense plasma. The core of a fusion reactor would consist of burning plasma. Fusion would occur between the nuclei, with the electrons present only to maintain macroscopic charge neutrality.

Stars, including the Sun, consist of plasmas that generate energy by fusion reactions. In these "natural fusion reactors" the reacting, or burning, plasma is confined by its own gravity. It is not possible to assemble on Earth a plasma sufficiently massive to be gravitationally confined. The hydrogen bomb is an example of fusion reactions produced in an uncontrolled, unconfined manner in which the energy density is so high that the energy release is explosive. By contrast, the use of fusion for peaceful energy generation requires control and confinement of a plasma at high temperature and is often called controlled thermonuclear fusion.

In the development of fusion power technology, demonstration of "energy breakeven" is taken to signify the scientific feasibility of fusion. At breakeven, the fusion power produced by a plasma is equal to the power input to maintain the plasma. This requires a plasma that is hot, dense, and well confined. The temperature required, about 100 million kelvins, is several times that of the Sun. The product of the density and energy confinement time of the plasma (the time it takes the plasma to lose its energy if unreplaced) must exceed a critical value.

Principal approaches to controlled thermonuclear fusion

There are two main approaches to controlled fusion—namely, magnetic confinement and inertial confinement. In magnetic confinement, a low-density plasma is confined for a long period of time by a magnetic field. The plasma density is roughly 10^{15} particles per cubic centimetre, which is many thousands of times less than the density of air at room temperature. The energy confinement time must then be at least one second—*i.e.*, the energy in the plasma must be replaced every second. In inertial confinement, no attempt is made to confine the plasma beyond the time it takes the plasma to disassemble. The energy confinement time is simply the time it takes the fusing plasma to expand. Confined only by its own inertia, the plasma survives for only about one-billionth of a second (one nanosecond). Hence, breakeven in this scheme requires a very large density of particles, typically about 10^{24} particles per cubic centimetre, which is about 100 times the density of a liquid. The extremely high density is achieved by compressing a solid pellet of fuel by the pressure of incident laser or particle beams. These approaches are sometimes referred to as laser fusion or particle-beam fusion.

The fusion reaction least difficult to achieve combines a deuteron (the nucleus of the deuterium atom) with a triton (the nucleus of a tritium atom). Both nuclei are isotopes of the hydrogen nucleus and contain a single unit of positive electric charge. Deuterium–tritium (D–T) fusion thus requires the nuclei to have lower kinetic energy than is needed for the fusion of more highly charged, heavier nuclei. The two products of the reaction are an alpha particle (nucleus of the helium atom) at an energy of 3.5 million electron volts (MeV) and a neutron at an energy of 14.1 MeV. (One MeV is the energy equivalent of 10 billion kelvins.) The neutron, lacking electric charge, is not affected by electric or magnetic fields within the plasma and can escape the plasma to deposit its energy in a material, such as lithium, which can surround the plasma. The heat generated in the lithium blanket is then converted to electrical energy by conventional means, such as turbines. The electrically charged alpha particle collides with the deuterons and tritons (by their electrical interaction) and can be magnetically confined within the plasma. It thereby transfers its energy to the reacting nuclei. When this redeposition of the fusion energy into the plasma exceeds the power lost from the plasma (by electromagnetic radiation, conduction, and convection), the plasma will be self-sustaining, or "ignited."

Inexhaustible source of energy

With deuterium and tritium as the fuel, the fusion reactor would be an effectively inexhaustible source of energy. Deuterium is obtained from seawater. About one in every 3,000 water molecules contains a deuterium atom. There is enough deuterium in the oceans to provide for the world's energy needs for billions of years. One gram of fusion fuel can produce as much energy as 9,000 litres of oil. The amount of deuterium found naturally in one litre of water is the energy equivalent of 300 litres of gasoline. Tritium is bred in the fusion reactor. It is generated in the lithium blanket as a product of the reaction in which neutrons are captured by the lithium nuclei.

A fusion reactor would have several attractive safety features. First, it is not subject to a runaway, or "meltdown," accident as is a fission reactor. The fusion reaction is not a chain reaction. It requires a hot plasma. Accidental interruption of a plasma control system would extinguish

the plasma and terminate fusion. Second, the products of a fusion reaction are not radioactive; hence, no long-term radioactive wastes would be generated. Neutron bombardment would activate the walls of the containment vessel, but such activated material is shorter-lived and less toxic than the waste products of a fission reactor. (Moreover, even this activation problem may be eliminated, either by the development of advanced, low-activation materials or by the employment of "advanced" fusion-fuel cycles that do not produce neutrons.) Finally, a fusion reactor would not release the gaseous pollutants that accompany the combustion of fossil fuels; hence, fusion would not produce a greenhouse effect.

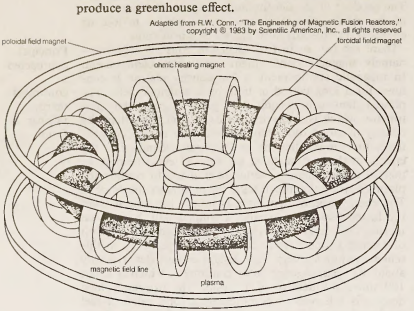

Figure 87: Tokamak magnetic confinement.

Principles of magnetic confinement. *Confinement physics.* Magnetic confinement of plasmas is the most highly developed approach to controlled fusion. The hot plasma is contained by magnetic forces exerted on the charged particles. A large part of the problem of fusion has been the attainment of magnetic field configurations that effectively confine the plasma. A successful configuration must meet three criteria: (1) the plasma must be in a time-independent equilibrium state, (2) the equilibrium must be macroscopically stable, and (3) the leakage of plasma energy to the bounding wall must be small.

Basic requirements

A single charged particle tends to spiral about a magnetic line of force. It is necessary that the single particle trajectories do not intersect the wall. Moreover, the pressure force, arising from the thermal energy of all the particles, is in a direction to expand the plasma. For the plasma to be in equilibrium, the magnetic force acting on the electric current within the plasma must balance the pressure force at every point in the plasma.

The equilibrium thus obtained has to be stable. A plasma is continually perturbed by random thermal "noise" fluctuations. If unstable, it might depart from its equilibrium state and rapidly escape the confines of the magnetic field.

A plasma in stable equilibrium can be maintained indefinitely if the leakage of energy from the plasma is balanced by energy input. If the plasma energy loss is too large, then ignition cannot be achieved. An unavoidable diffusion of energy across the magnetic field lines will occur from the collisions between the particles. The net effect is to transport energy from the hot core to the wall. This transport process, known as classical diffusion, is theoretically not strong in hot fusion plasmas. In experiments, however, energy is lost from plasma more rapidly than would be expected from classical diffusion. The observed energy loss typically exceeds the classical value by a factor of 10–100. Reduction of this anomalous transport is important to the engineering feasibility of fusion. An understanding of anomalous transport in plasmas in terms of physics is not yet in hand. However, turbulently fluctuating electric and magnetic fields can push particles across the confining magnetic field.

Types of magnetic configurations

Many different types of magnetic configurations for plasma confinement have been devised and tested over the years. This has resulted in a family of related magnetic configurations, which may be grouped into two classes: closed, toroidal configurations and open, linear configurations. Toroidal devices are the most highly developed. In a simple straight magnetic field the plasma would be free to stream out the ends. End loss can be eliminated by forming the plasma and field in the closed shape of a doughnut, or torus, or, in an approach called mirror confinement, by "plugging" the ends of such a device magnetically and electrostatically.

Toroidal confinement. The most extensively investigated toroidal confinement concept is the tokamak (Figure 87). The tokamak (an acronym derived from the Russian words for toroidal magnetic confinement) was introduced in the mid-1960s by Soviet plasma physicists. The magnetic lines of force are helixes that spiral around the torus. The helical magnetic field has two components: (1) a toroidal component, which points the long way around the torus, and (2) a poloidal component directed the short way around the machine. The toroidal field is produced by coils that surround the toroidal vacuum chamber containing the plasma. (The plasma must be situated within an evacuated chamber to prevent it from being cooled by interactions with air molecules.) The poloidal field is generated by a toroidal electric current that is forced to flow within the conducting plasma. Both components are necessary for the plasma to be in stable equilibrium. If the poloidal field were zero, particles would not strictly follow the field lines but would drift to the walls. The addition of the poloidal field provides particle orbits that are contained within the device. If the toroidal field were zero, the plasma would be in equilibrium but it would be unstable. The plasma column would develop growing distortions, or kinks, which would carry the plasma into the wall.

The tokamak

Several novel methods have been developed to drive the steady-state current that produces the poloidal magnetic field. A technique known as radio-frequency (RF) current drive employs electromagnetic waves to generate the current. Electromagnetic waves are injected into the plasma so that they propagate within the plasma in one direction around the torus. The speed of the waves is chosen to equal roughly the average speed of the electrons in the plasma. The wave electric field can then continuously accelerate the electrons as the wave and particles move together around the torus. The electrons develop a net motion, or current, in one direction. Although this technique is now well established, its efficiency is reduced at the density of a reacting plasma.

RF current drive

Another established current-drive technique is neutral-beam current drive. A beam of high-energy neutral atoms is injected into the plasma along the toroidal direction. The neutral beam will freely enter the plasma since it is unaffected by the magnetic field. The neutral atoms become ionized by collisions with the electrons. The beam then consists of energetic positively charged nuclei that are confined within the plasma by the magnetic field. The high-speed ions travel toroidally along the magnetic field and collide with the electrons, pushing them in one direction and thereby producing a current.

Neutral-beam current drive

A remarkable effect occurs in tokamak plasmas that reduces the need for external current drive. If the plasma pressure is greater in the core than at the edge, this pressure differential spontaneously drives a toroidal current in the plasma. This current is called the "bootstrap current." It can be considered a type of thermoelectric effect, but its origin is in the complex particle dynamics that arise in a toroidal plasma. It has been observed in experiment and is now included routinely in tokamak reactor designs.

Faraday induction, or "ohmic current drive," can be used to initiate and build up the current. A magnetic flux that increases over time is produced through the hole in the torus. The plasma surrounds the flux. The time-varying flux induces a toroidal electric field that drives the plasma current. This technique efficiently drives a pulsed plasma current; however, it cannot be used for a steady-state current, which would require a magnetic flux increasing indefinitely over time.

The plasma in a tokamak fusion reactor would have a major diameter in the range of 10 metres and a minor di-

ameter of roughly three metres. The plasma current would likely be tens of millions of amperes and the toroidal magnetic field several teslas. The coils that produce the strong toroidal magnetic field would probably be superconducting in order to minimize power dissipation.

Other toroidal confinement concepts that offer potential advantages over the tokamak are being developed, albeit less energetically than the tokamak. Three such alternatives are the stellarator, reversed-field pinch (RFP), and compact torus concepts. The stellarator and RFP are much like the tokamak. In the stellarator the magnetic field is produced by external coils only; the plasma current is essentially zero. Hence, the problems inherent in sustaining a large plasma current are absent. The RFP differs from the tokamak in that it operates with a weak toroidal magnetic field. This results in a compact, high-power-density reactor with ordinary (instead of superconducting) coils. Compact tori are toroidal plasmas with no hole in the center of the torus (aspect ratio of one). Reactors based on compact tori are small and avoid the engineering complications of coils linking the plasma torus.

Mirror confinement. An alternative approach to magnetic confinement is to employ a straight configuration in which the end loss is reduced by a combination of magnetic and electric plugging. In such a linear fusion reactor the magnetic field strength is increased at the ends. Charged particles that approach the end slow down, and many are reflected from this "magnetic mirror." Unfortunately, particles with extremely high speed along the field are not stopped by the mirror. To inhibit this leakage, electrostatic plugging is provided. An additional section of plasma is added at each end beyond the magnetic mirror. The plasma in these "end plugs" produces an electrostatic potential barrier to nuclei. The overall configuration is called a tandem mirror.

Plasma heating. A fusion reactor requires tens of megawatts of heating to reach ignition temperature. Two plasma-heating methods have been highly developed: electromagnetic wave heating and neutral-beam injection heating. In the former, electromagnetic waves are directed by antennas at the surface of the plasma. The waves penetrate the plasma and transfer their energy to the constituent particles. Effective wave-heating techniques employ frequencies from the radio-frequency range (tens of megahertz) to the microwave range (tens of gigahertz). Power absorption often relies upon a resonant interaction between the wave and plasma. This technique is called ion cyclotron resonance heating. Electron heating requires very high frequency (tens to hundreds of gigahertz). Recently developed free-electron lasers and gyrotron tubes are required at the highest frequencies.

In the second method, beams of neutral atoms at high energy (up to about one million electron volts) are injected into the plasma, rather as in the neutral-beam current drive described above. When used for heating, however, the beams are injected in both directions around the torus, so that no net momentum is imparted to the plasma. The slowing down, or transfer of beam energy to the plasma, constitutes the heating mechanism.

Principles of inertial confinement. In an inertial confinement fusion (ICF) reactor a tiny solid pellet of fuel (such as deuterium–tritium) would be compressed to tremendous density and temperature so that fusion power is produced in the very short time (tens of nanoseconds) before the pellet blows apart. The compression is accomplished by focusing an intense laser beam (or a charged particle beam) upon the small pellet (typically one to 10 millimetres in diameter). The surface of the pellet is ionized by the beam. The ablation of the ionized material generates a large inward force on the pellet (as in the rocket effect), which compresses the pellet to 1,000 to 10,000 times liquid density. During compression the temperature of the pellet increases to a value sufficient to produce fusion reactions (Figure 88). Ignition occurs, and the pellet, now a dense plasma, is burned up in a small micro-explosion. The process is repeated between one and 100 times per second.

Laser fusion

Inertial confinement fusion has been compared to the four-stage internal-combustion engine. In the fuel-injection stage, the pellet is injected into a blast chamber. In the compression stage, the pellet is compressed by the driver beams (laser or charged particle). In the ignition stage, the fusion reactions begin. In the final stage, the burn proceeds to completion and the fusion reaction products (neutrons, X rays, and charged particles) bombard and heat a blanket.

For efficient thermonuclear burn, the time to burn the pellet must be less than the disassembly time. This yields a criterion that in the compressed state the product of the pellet mass density and the pellet radius exceed about three grams per square centimetre. A high mass density will hasten the burn, and a large radius will slow the disassembly time. This criterion can be satisfied, for example, with a one-millimetre pellet and a fuel density of 30 grams per cubic centimetre. This density requires pellet compression to about 150 times its initial density (4.5×10^{22} particles per cubic centimetre).

The two key components of an ICF reactor are the driver beams and pellets. The power requirement of the driver beams is influenced by the efficiency of the driver (conversion of electrical power to beam power) and the efficiency at which the driver energy is absorbed by the pellet. At present, each of these efficiencies is between 1 and 10 percent for laser fusion. To overcome these losses requires an energy gain Q (fusion power/absorbed power) of about 1,000 to 10,000. An energy of one to five megajoules must be delivered to the pellet in one to 10 nanoseconds. The laser irradiation must strike the pellet surface uniformly to compress the pellet effectively. Thus, many laser beams irradiate the pellet with approximate spherical symmetry (see Figure 88).

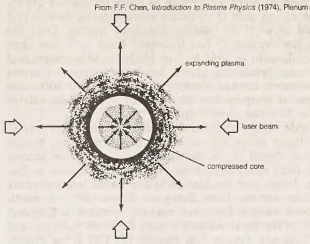

Figure 88: Laser fusion.

Particle beam fusion

Charged particle driver beams can offer the advantage of more efficient production and absorption. Beams of electrons would "defocus" as a result of the small electron mass. For this reason, light ion or heavy ion beams are employed. Beams of light ions (hydrogen through carbon) in the MeV energy range are produced by pulsed-power diode accelerators. In such accelerators, large voltage between a cathode and anode applies a strong electric force on the particles. The expected efficiency of light ion production is approximately 30 percent. Beams of heavy ions (xenon to uranium) are accelerated to energies of one billion electron volts (GeV) using accelerator technology from high-energy physics experiments. Accelerators of this type push particles either by induction or with electromagnetic waves.

The pellets that currently are used are multilayered, consisting of several concentric spheres. A difference in pellet design is largely the basis of the distinction made between "direct" and "indirect" drive ICF. In indirect drive, the outer layer generates X rays, which in turn drive the implosion process through the ablation layer. This step diffuses the driver energy so that its effect is highly symmetrical. In direct drive, the driver energy is absorbed by the ablation layer itself, requiring far greater symmetry in irradiance of the target.

In both approaches the ablation layer is converted to a plasma and blown away. In the plasma state, the high

heat conduction symmetrizes the ablation process. The ablation layer surrounds a thick, heavy material of high atomic mass. The recoil from the ablation implodes the heavy layer, producing a shock wave that compresses and heats the next inner layer of deuterium–tritium fuel. The implosion speed is several hundred kilometres per second, produced by a force equivalent to some 10 billion atmospheres. The heavy layer inhibits the growth of instabilities that would interfere with the compression. It also prevents the high-energy electrons and protons from the corona plasma from heating the deuterium–tritium layer. The laser energy provides compression, not heat (entropy). The burn initiates in the D–T layer and spreads outward as the alpha particles collide with and heat the rest of the pellet to thermonuclear temperature.

Development of fusion reactor technology. *Magnetic confinement.* Several decades of fusion research have produced accomplishments of two types. First, the discipline of plasma physics has developed to the point that theoretical and experimental tools permit quantitative evaluation of many aspects of fusion reactor concepts. Second, and perhaps most revealing, the evolutionary improvement of plasma parameters has placed experiments at the threshold of energy breakeven.

Fusion research experiments are performed with hydrogen or deuterium plasmas in most cases. For years, radioactive tritium was not added, because remote-handling requirements complicated the experiments. However, in 1991 the first tritium–deuterium reaction was carried out. The "burn" lasted for two seconds and released a record amount of energy, approximately 20 times that released in deuterium–deuterium experiments.

A figure of merit with which to judge the plasma quality is the energy gain Q (= fusion power/heating power) that would occur if the plasma contained tritium. Over the past few decades Q has increased from 10^{-7} (less than one-millionth) in 1965 to 1 in 1995; the long-sought goal of energy breakeven, $Q = 1$, has been achieved. Current experiments confine plasmas with volumes of 100 cubic metres at temperatures in excess of 100 million kelvins (up to 30 kiloelectron volts).

A wide variety of plasma experiments are under way to investigate many aspects of the fusion problem. Performances closest to the level of a practical fusion reactor have been attained in three flagship experiments in Europe, Japan, and the United States. These large tokamak facilities are the Joint European Torus (JET), a multinational western European venture operated in England; JT-60 of the Japan Atomic Energy Research Institute; and the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory.

In 1994 a major milestone was achieved when the TFTR device generated 10 megawatts of fusion power. Theretofore, nearly all fusion experiments were operated with hydrogen or deuterium plasmas. TFTR was fueled with a mix of deuterium and tritium. Experimentation with fusing plasmas is critical to establish the effect of the fusion reactions (and the high-energy alpha particles that they produce) on plasma behaviour. Interestingly, the confinement of the plasma energy improved modestly in D–T plasmas, compared to that in pure deuterium, a promising effect that is not yet understood.

A next major step in the development of fusion power is the construction of a facility to study the physics of a burning, ignited plasma (with Q being infinite). The presence of alpha particles can alter the behaviour of the plasma in ways not easily simulated in nonburning plasmas. It is anticipated that this would occur in a planned new experiment, the International Thermonuclear Experimental Reactor (ITER). This is a very large experiment that would investigate both the physics of an ignited plasma and reactor technology. ITER would generate about 1.5 billion watts of thermal fusion power (which would not be converted to electricity). The large cost of the device (in the range of $10 billion) has encouraged international collaboration, and from its conception ITER has involved as equal partners the European Union, Japan, Russia, and the United States. The engineering design is expected to be complete by 1998, with operation beginning about 2010. It is hoped that ITER would be followed by a demonstration fusion reactor power plant.

With the tremendous advances in scientific understanding and plasma quality, questions regarding the engineering and economic attractiveness of the tokamak concept have received greater attention. Materials development is required. For example, the wall exposed to the plasma must survive intense neutron bombardment. The optimal path to fusion-energy production involves some balance between further upscaling of the current tokamak concept toward reactor parameters and improvement of the magnetic confinement concept. Improvements can accrue from enhanced scientific understanding through research and by the development of alternative, non-tokamak concepts, as well as improvements to the tokamak. A significant thrust in tokamak research is to develop more compact tokamaks with higher plasma pressure. Such advanced tokamaks are expected to be more economical.

Inertial confinement. ICF research has followed an evolutionary path similar to that of magnetic fusion. In the laser fusion approach, densities ranging from 100 to 200 times liquid deuterium–tritium density have been achieved. For example, at the Lawrence Livermore National Laboratory in California, a product of density and energy-confinement time of 5×10^{14} seconds per cubic centimetre has been achieved employing the world's largest and most powerful laser, the so-called Nova laser. (The Nova is a 10-beam neodymium–glass laser operated at an energy level of 40,000 joules in a one-nanosecond pulse.) Although the value of this product is comparable to that representing breakeven for magnetic fusion, laser fusion requires a larger value to overcome the rather poor efficiency of existing lasers.

Nova laser

As a result of such progress there are plans in the United States to construct the National Ignition Facility, a laser fusion experiment that will achieve ignition. However, this facility, to be located at the Lawrence Livermore National Laboratory, is funded primarily for its application to weapons research, not energy research. Light-ion beam experiments are also making headway. Scientists at the Particle Beam Fusion Accelerator (PBFA) at Sandia National Laboratories in New Mexico have demonstrated the ability to focus 72 beams to a spot diameter of less than six millimetres. One objective is to achieve an intensity of 10 terawatts per cubic centimetre (100 terawatts per cubic centimetre are required in a practical fusion reactor).

In both the magnetic and inertial confinement programs, the experimental steps become increasingly more expensive as the reactor regime is approached. At the same time, basic research and innovation are needed to enhance the attractiveness of the reactor concepts. Significant wisdom is required to balance these needs and to build effectively upon the impressive results to date so that nuclear fusion can indeed become a major factor in meeting the world's ever-growing energy needs. (S.C.P./Ed.)

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Engineering

Engineering is the professional art of applying science to the optimum conversion of the resources of nature to the uses of humankind. Engineering has been defined by the Engineers Council for Professional Development, in the United States, as the creative application of "scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behaviour under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property." The term engineering is sometimes more loosely defined, especially in Great Britain, as the manufacture or assembly of engines, machine tools, and machine parts.

The words engine and ingenious are derived from the same Latin root, *ingenerare,* which means "to create." The early English verb *engine* meant "to contrive." Thus the engines of war were devices such as catapults, floating bridges, and assault towers; their designer was the "engine-er," or military engineer. The counterpart of the military engineer was the civil engineer, who applied essentially the same knowledge and skills to designing buildings, streets, water supplies, sewage systems, and other projects.

Associated with engineering is a great body of special knowledge; preparation for professional practice involves extensive training in the application of that knowledge. Standards of engineering practice are maintained through the efforts of professional societies, usually organized on a national or regional basis, with each member acknowledging a responsibility to the public over and above responsibilities to his employer or to other members of his society.

The function of the scientist is to know, while that of the engineer is to do. The scientist adds to the store of verified, systematized knowledge of the physical world; the engineer brings this knowledge to bear on practical problems. Engineering is based principally on physics, chemistry, and mathematics and their extensions into materials science, solid and fluid mechanics, thermodynamics, transfer and rate processes, and systems analysis.

Unlike the scientist, the engineer is not free to select the problem that interests him; he must solve problems as they arise; his solution must satisfy conflicting requirements. Usually efficiency costs money; safety adds to complexity; improved performance increases weight. The engineering solution is the optimum solution, the end result that, taking many factors into account, is most desirable. It may be the most reliable within a given weight limit, the simplest that will satisfy certain safety requirements, or the most efficient for a given cost. In many engineering problems the social costs are significant.

Engineers employ two types of natural resources—materials and energy. Materials are useful because of their properties: their strength, ease of fabrication, lightness, or durability; their ability to insulate or conduct; their chemical, electrical, or acoustical properties. Important sources of energy include fossil fuels (coal, petroleum, gas), wind, sunlight, falling water, and nuclear fission. Since most resources are limited, the engineer must concern himself with the continual development of new resources as well as the efficient utilization of existing ones.

For the history and functions of industrial engineering, see INDUSTRIAL ENGINEERING AND PRODUCT MANAGEMENT.

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Engineering as a profession

HISTORY OF ENGINEERING

The first engineer known by name and achievement is Imhotep, builder of the Step Pyramid at Ṣaqqārah, Egypt, probably in about 2550 BC. Imhotep's successors—Egyptian, Persian, Greek, and Roman—carried civil engineering to remarkable heights on the basis of empirical methods aided by arithmetic, geometry, and a smattering of physical science. The Pharos (lighthouse) of Alexandria, Solomon's Temple in Jerusalem, the Colosseum in Rome, the Persian and Roman road systems, the Pont du Gard aqueduct in France, and many other large structures, some of which endure to this day, testify to their skill, imagination, and daring. Of many treatises written by them, one in particular survives to provide a picture of engineering education and practice in classical times: Vitruvius' *De architectura,* published in Rome in the 1st century AD, a 10-volume work covering building materials, construction methods, hydraulics, measurement, and town planning.

In construction medieval European engineers carried technique, in the form of the Gothic arch and flying buttress, to a height unknown to the Romans. The sketchbook of the 13th-century French engineer Villard de Honnecourt reveals a wide knowledge of mathematics, geometry, natural and physical science, and draftsmanship.

In Asia, engineering had a separate but very similar development, with more and more sophisticated techniques of construction, hydraulics, and metallurgy helping to create advanced civilizations such as the Mongol empire, whose large, beautiful cities impressed Marco Polo in the 13th century.

Civil engineering emerged as a separate discipline in the 18th century, when the first professional societies and

Civil and mechanical engineering

schools of engineering were founded. Civil engineers of the 19th century built structures of all kinds, designed water-supply and sanitation systems, laid out railroad and highway networks, and planned cities. England and Scotland were the birthplace of mechanical engineering, as a derivation of the inventions of the Scottish engineer James Watt and the textile machinists of the Industrial Revolution. The development of the British machine-tool industry gave tremendous impetus to the study of mechanical engineering both in Britain and abroad.

The growth of knowledge of electricity—from Alessandro Volta's original electric cell of 1800 through the experiments of Michael Faraday and others, culminating in 1872 in the Gramme dynamo and electric motor (named after the Belgian Z.T. Gramme)—led to the development of electrical and electronics engineering. The electronics aspect became prominent through the work of such scientists as James Clerk Maxwell of Britain and Heinrich Hertz of Germany in the late 19th century. Major advances came with the development of the vacuum tube by Lee De Forest of the United States in the early 20th century and the invention of the transistor in the mid-20th century. In the late 20th century electrical and electronics engineers outnumbered all others in the world.

Chemical engineering

Chemical engineering grew out of the 19th-century proliferation of industrial processes involving chemical reactions in metallurgy, food, textiles, and many other areas. By 1880 the use of chemicals in manufacturing had created an industry whose function was the mass production of chemicals. The design and operation of the plants of this industry became a function of the chemical engineer.

ENGINEERING FUNCTIONS

Problem solving is common to all engineering work. The problem may involve quantitative or qualitative factors; it may be physical or economic; it may require abstract mathematics or common sense. Of great importance is the process of creative synthesis or design, putting ideas together to create a new and optimum solution.

Although engineering problems vary in scope and complexity, the same general approach is applicable. First comes an analysis of the situation and a preliminary decision on a plan of attack. In line with this plan, the problem is reduced to a more categorical question that can be clearly stated. The stated question is then answered by deductive reasoning from known principles or by creative synthesis, as in a new design. The answer or design is always checked for accuracy and adequacy. Finally, the results for the simplified problem are interpreted in terms of the original problem and reported in an appropriate form.

In order of decreasing emphasis on science, the major functions of all engineering branches are the following:

Research. Using mathematical and scientific concepts, experimental techniques, and inductive reasoning, the research engineer seeks new principles and processes.

Development. Development engineers apply the results of research to useful purposes. Creative application of new knowledge may result in a working model of a new electrical circuit, a chemical process, or an industrial machine.

Design. In designing a structure or a product, the engineer selects methods, specifies materials, and determines shapes to satisfy technical requirements and to meet performance specifications.

Construction. The construction engineer is responsible for preparing the site, determining procedures that will economically and safely yield the desired quality, directing the placement of materials, and organizing the personnel and equipment.

Production. Plant layout and equipment selection are the responsibility of the production engineer, who chooses processes and tools, integrates the flow of materials and components, and provides for testing and inspection.

Operation. The operating engineer controls machines, plants, and organizations providing power, transportation, and communication; determines procedures; and supervises personnel to obtain reliable and economic operation of complex equipment.

Management and other functions. In some countries and industries, engineers analyze customers' requirements, recommend units to satisfy needs economically, and resolve related problems. (R.J.Sm./Ed.)

Major fields of engineering

MILITARY ENGINEERING

In its earliest uses the term engineering referred particularly to the construction of engines of war and the execution of works intended to serve military purposes. Military engineers were long the only ones to whom the title engineer was applied.

The role of the military engineer in modern war is to apply engineering knowledge and resources to the furtherance of the commander's plans. The basic requirement is a sound general engineering knowledge directed to the technical aspects of those tasks likely to be encountered in war. Engineering work is influenced by topographical considerations and in battle also by tactical limitations. At times engineering factors will actually govern the choice of the military plan adopted; a military engineer must, therefore, possess a sound military education so that the best technical advice will be given to the commander.

History. In the prehistoric period every man was a fighter and every fighter was to some extent an engineer. Primitive efforts were restricted to the provision of artificial protection for the person and machines for hurling destruction at the enemy. In the earliest war annals it is difficult to distinguish the military from the civil engineer. Julius Caesar referred to his *praefectus fabrum*, an official who controlled the labour gangs employed on road making and also parties of artisans. The Domesday survey of AD 1086 included one "Waldivus Ingeniator," who held nine manors direct from the crown and was probably William the Conqueror's chief engineer in England. Throughout the Middle Ages, ecclesiastics were frequently employed as military engineers, not only for purposes of planning and building but also for fighting. One of the best known is Gundulph, bishop of Rochester, who built the White Tower of the Tower of London and Rochester Castle.

Thus, in ancient and medieval times the military engineer became a specialist who made and used engines of war such as catapults, ballistas, battering rams, ramps, towers, scaling ladders, and other devices in attacking or defending castles, fortresses, and fortified camps. In peacetime the military engineer built fortifications for the defense of the country or city. Because such engineers frequently dug trenches or tunnels as means of approaching or undermining enemy positions, they came to be called sappers or miners. With the invention of gunpowder and the countless other inventions that came in later centuries, the military engineer was required to have far more technical knowledge. He nevertheless remained a soldier and fought side by side with the infantry in many wars.

The French corps of engineers

Before the late 17th century the engineers of French armies were selected infantry officers given brevets as engineers; they performed both civil and military duties for the king's service. In 1673 Sébastien Le Prestre de Vauban was appointed director general of the royal fortifications, and it was largely owing to this great designer of fortified places that in 1690 an officer corps of engineers was established. Sapper and miner companies were formed later, although these units were generally attached to the artillery. In 1801 the officer corps of engineers was integrated with the sapper and miner units, and the amalgamated corps served with great distinction throughout Napoleon's campaigns. In 1868 military telegraphists were added to the corps. The first engineer railway battalion was formed in 1876, and a battalion of aeronauts raised in 1904 was the forerunner of the French air force.

The first military engineering school was established at Mézières in 1748, and Lazare Carnot, a former graduate of Mézières, moved the school to Metz in 1795, where it was renamed the École Polytechnique ("Polytechnic School").

Military engineering functions. The functions of modern military engineers vary among the armies of the world, but as a rule they include the following activities: (1) construction and maintenance of roads, bridges, airfields, landing strips, and zones for the airdrop of personnel and supplies, (2) interference with the enemy's mobility

by means of demolitions, floods, destruction of matériel, mine fields, and obstacles and fortifications of many types, (3) mapping and aiding the artillery to survey gun positions, rocket-launching sites, and target areas, (4) supplying water and engineering equipment, and (5) disposal of unexploded bombs or warheads. In the British army the Royal Engineers also operate the army postal service.

The U.S. Army Corps of Engineers is both a combatant arm and a technical service. Alone among the arms and services, it engages in civil as well as military activities. During the 20th century its civil works activities have centred upon the planning, construction, and maintenance of improvements to rivers, harbours, and other waterways and upon flood control. The principal military service performed by the Corps of Engineers in the United States and abroad is the construction and maintenance of buildings and utilities. In theatres of operation in wartime, such construction is carried out by engineer troops. In the United States in peace and war and overseas in peacetime, such construction is usually accomplished by private industry under contract to the Corps of Engineers. (Ed.)

CIVIL ENGINEERING

The term civil engineering was first used in the 18th century to distinguish the newly recognized profession from military engineering, until then preeminent. From earliest times, however, engineers have engaged in peaceful activities, and many of the civil engineering works of ancient and medieval times—such as the Roman public baths, roads, bridges, and aqueducts; the Flemish canals; the Dutch sea defenses; the French Gothic cathedrals; and many other monuments—reveal a history of inventive genius and persistent experimentation.

History. The beginnings of civil engineering as a separate discipline may be seen in the foundation in France in 1716 of the Bridge and Highway Corps, out of which in 1747 grew the École Nationale des Ponts et Chaussées ("National School of Bridges and Highways"). Its teachers wrote books that became standard works on the mechanics of materials, machines, and hydraulics, and leading British engineers learned French to read them. As design and calculation replaced rule of thumb and empirical formulas, and as expert knowledge was codified and formulated, the nonmilitary engineer moved to the front of the stage. Talented, if often self-taught, craftsmen, stonemasons, millwrights, toolmakers, and instrument makers became civil engineers. In Britain, James Brindley began as a millwright and became the foremost canal builder of the century; John Rennie was a millwright's apprentice who eventually built the new London Bridge; Thomas Telford, a stonemason, became Britain's leading road builder.

Smeaton's work

John Smeaton, the first man to call himself a civil engineer, began as an instrument maker. His design of Eddystone Lighthouse (1756–59), with its interlocking masonry, was based on a craftsman's experience. Smeaton's work was backed by thorough research, and his services were much in demand. In 1771 he founded the Society of Civil Engineers (now known as the Smeatonian Society). Its object was to bring together experienced engineers, entrepreneurs, and lawyers to promote the building of large public works, such as canals (and later railways), and to secure the parliamentary powers necessary to execute their schemes. Their meetings were held during parliamentary sessions; the society follows this custom to this day.

The École Polytechnique was founded in Paris in 1794, and the Bauakademie was started in Berlin in 1799, but no such schools existed in Great Britain for another two decades. It was this lack of opportunity for scientific study and for the exchange of experiences that led a group of young men in 1818 to found the Institution of Civil Engineers. The founders were keen to learn from one another and from their elders, and in 1820 they invited Thomas Telford, by then the dean of British civil engineers, to be their first president. There were similar developments elsewhere. By the mid-19th century there were civil engineering societies in many European countries and the United States, and the following century produced similar institutions in almost every country in the world.

Formal education in engineering science became widely available as other countries followed the lead of France and Germany. In Great Britain the universities, traditionally seats of classical learning, were reluctant to embrace the new disciplines. University College, London, founded in 1826, provided a broad range of academic studies and offered a course in mechanical philosophy. King's College, London, first taught civil engineering in 1838, and in 1840 Queen Victoria founded the first chair of civil engineering and mechanics at the University of Glasgow, Scot. Rensselaer Polytechnic Institute, founded in 1824, offered the first courses in civil engineering in the United States. The number of universities throughout the world with engineering faculties, including civil engineering, increased rapidly in the 19th and early 20th centuries. Civil engineering today is taught in universities on every continent.

Engineering education

Civil engineering functions. The functions of the civil engineer can be divided into three categories: those performed before construction (feasibility studies, site investigations, and design), those performed during construction (dealing with clients, consulting engineers, and contractors), and those performed after construction (maintenance and research).

Feasibility studies. No major project today is started without an extensive study of the objective and without preliminary studies of possible plans leading to a recommended scheme, perhaps with alternatives. Feasibility studies may cover alternative methods—*e.g.,* bridge versus tunnel, in the case of a water crossing—or, once the method is decided, the choice of route. Both economic and engineering problems must be considered.

Site investigations. A preliminary site investigation is part of the feasibility study, but once a plan has been adopted a more extensive investigation is usually imperative. Money spent in a rigorous study of ground and substructure may save large sums later in remedial works or in changes made necessary in constructional methods.

Since the load-bearing qualities and stability of the ground are such important factors in any large-scale construction, it is surprising that a serious study of soil mechanics did not develop until the mid-1930s. Karl von Terzaghi, the chief founder of the science, gives the date of its birth as 1936, when the First International Conference on Soil Mechanics and Foundation Engineering was held at Harvard University and an international society was formed. Today there are specialist societies and journals in many countries, and most universities that have a civil engineering faculty have courses in soil mechanics.

Soil mechanics

Design. The design of engineering works may require the application of design theory from many fields—*e.g.,* hydraulics, thermodynamics, or nuclear physics. Research in structural analysis and the technology of materials has opened the way for more rational designs, new design concepts, and greater economy of materials. The theory of structures and the study of materials have advanced together as more and more refined stress analysis of structures and systematic testing has been done. Modern designers not only have advanced theories and readily available design data, but structural designs can now be rigorously analyzed by computers.

Construction. The promotion of civil engineering works may be initiated by a private client, but most work is undertaken for large corporations, government authorities, and public boards and authorities. Many of these have their own engineering staffs, but for large specialized projects it is usual to employ consulting engineers.

The role of the consulting engineer

The consulting engineer may be required first to undertake feasibility studies, then to recommend a scheme and quote an approximate cost. The engineer is responsible for the design of the works, supplying specifications, drawings, and legal documents in sufficient detail to seek competitive tender prices. The engineer must compare quotations and recommend acceptance of one of them. Although he is not a party to the contract, the engineer's duties are defined in it; the staff must supervise the construction and the engineer must certify completion of the work. Actions must be consistent with duty to the client; the professional organizations exercise disciplinary control over professional conduct. The consulting engineer's senior representative on the site is the resident engineer.

A phenomenon of recent years has been the turnkey or package contract, in which the contractor undertakes to finance, design, specify, construct, and commission a project in its entirety. In this case, the consulting engineer is engaged by the contractor rather than by the client.

The contractor is usually an incorporated company, which secures the contract on the basis of the consulting engineer's specification and general drawings. The consulting engineer must agree to any variations introduced and must approve the detailed drawings.

Maintenance. The contractor maintains the works to the satisfaction of the consulting engineer. Responsibility for maintenance extends to ancillary and temporary works where these form part of the overall construction. After construction a period of maintenance is undertaken by the contractor, and the payment of the final installment of the contract price is held back until released by the consulting engineer. Central and local government engineering and public works departments are concerned primarily with maintenance, for which they employ direct labour.

Research. Research in the civil engineering field is undertaken by government agencies, industrial foundations, the universities, and other institutions. Most countries have government-controlled agencies, such as the United States Bureau of Standards and the National Physical Laboratory of Great Britain, involved in a broad spectrum of research, and establishments in building research, roads and highways, hydraulic research, water pollution, and other areas. Many are government-aided but depend partly on income from research work promoted by industry.

Branches of civil engineering. In 1828 Thomas Tredgold of England wrote:

> The most important object of Civil Engineering is to improve the means of production and of traffic in states, both for external and internal trade. It is applied in the construction and management of roads, bridges, railroads, aqueducts, canals, river navigation, docks and storehouses, for the convenience of internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters and lighthouses; and in the navigation by artificial power for the purposes of commerce.
>
> It is applied to the protection of property where natural powers are the sources of injury, as by embankments for the defence of tracts of country from the encroachments of the sea, or the overflowing of rivers; it also directs the means of applying streams and rivers to use, either as powers to work machines, or as supplies for the use of cities and towns, or for irrigation; as well as the means of removing noxious accumulations, as by the drainage of towns and districts to . . . secure the public health.

Aspects of civil engineering

A modern description would include the production and distribution of energy, the development of aircraft and airports, the construction of chemical process plants and nuclear power stations, and water desalination. These aspects of civil engineering may be considered under the following headings: construction, transportation, maritime and hydraulic engineering, power, and public health.

Construction. Almost all civil engineering contracts include some element of construction work. The development of steel and concrete as building materials had the effect of placing design more in the hands of the civil engineer than the architect. The engineer's analysis of a building problem, based on function and economics, determines the building's structural design.

Transportation. Roman roads and bridges were products of military engineering, but the pavements of McAdam and the bridges of Perronet were the work of the civil engineer. So were the canals of the 18th century and the railways of the 19th, which, by providing bulk transport with speed and economy, lent a powerful impetus to the Industrial Revolution. The civil engineer today is concerned with an even larger transportation field—*e.g.*, traffic studies, design of systems for road, rail, and air, and construction including pavements, embankments, bridges, and tunnels.

Maritime and hydraulic engineering. Harbour construction and shipbuilding are ancient arts. For many developing countries today the establishment of a large, efficient harbour is an early imperative, to serve as the inlet for industrial plant and needed raw materials and the outlet for finished goods. In developed countries the expansion of world trade, the use of larger ships, and the increase in total tonnage call for more rapid and efficient handling. Deeper berths and alongside-handling equipment (for example, for ore) and navigation improvements are the responsibility of the civil engineer.

The development of water supplies was a feature of the earliest civilizations, and the demand for water continues to rise today. In developed countries the demand is for industrial and domestic consumption, but in many parts of the world—*e.g.*, the Indus basin—vast schemes are under construction, mainly for irrigation to help satisfy the food demand, and are often combined with hydroelectric power generation to promote industrial development.

Dam engineering

Dams today are among the largest construction works, and design development is promoted by bodies like the International Commission on Large Dams. The design of large impounding dams in places with population centres close by requires the utmost in safety engineering, with emphasis on soil mechanics and stress analysis. Most governments exercise statutory control of engineers qualified to design and inspect dams.

Power. Civil engineers have always played an important part in mining for coal and metals; the driving of tunnels is a task common to many branches of civil engineering. In the 20th century the design and construction of power stations has advanced with the rapid rise in demand for electric power, and nuclear power stations have added a whole new field of design and construction, involving prestressed concrete pressure vessels for the reactor.

The exploitation of oil fields and the discoveries of natural gas in significant quantities have initiated a radical change in gas production. Shipment in liquid form from the Sahara and piping from the bed of the North Sea have been among the novel developments.

Public health. Drainage and liquid-waste disposal are closely associated with antipollution measures and the reuse of water. The urban development of parts of water catchment areas can alter the nature of runoff, and the training and regulation of rivers produce changes in the pattern of events, resulting in floods and the need for flood prevention and control.

Modern civilization has created problems of solid-waste disposal, from the manufacture of durable goods, such as automobiles and refrigerators, produced in large numbers with a limited life, to the small package, previously disposable, now often indestructible. The civil engineer plays an important role in the preservation of the environment, principally through design of works to enhance rather than to damage or pollute. (J.G.W./Ed.)

MECHANICAL ENGINEERING

Mechanical engineering is the branch of engineering that deals with machines and the production of power. It is particularly concerned with forces and motion.

Steam engine

History. The invention of the steam engine in the latter part of the 18th century, providing a key source of power for the Industrial Revolution, gave an enormous impetus to the development of machinery of all types. As a result, a new major classification of engineering dealing with tools and machines developed, receiving formal recognition in 1847 in the founding of the Institution of Mechanical Engineers in Birmingham, Eng.

Mechanical engineering has evolved from the practice by the mechanic of an art based largely on trial and error to the application by the professional engineer of the scientific method in research, design, and production. The demand for increased efficiency is continually raising the quality of work expected from a mechanical engineer and requiring a higher degree of education and training.

Mechanical engineering functions. Four functions of the mechanical engineer, common to all branches of mechanical engineering, can be cited. The first is the understanding of and dealing with the bases of mechanical science. These include dynamics, concerning the relation between forces and motion, such as in vibration; automatic control; thermodynamics, dealing with the relations among the various forms of heat, energy, and power; fluid flow; heat transfer; lubrication; and properties of materials.

Second is the sequence of research, design, and development. This function attempts to bring about the changes necessary to meet present and future needs. Such work requires a clear understanding of mechanical science, an ability to analyze a complex system into its basic factors, and the originality to synthesize and invent.

Third is production of products and power, which embraces planning, operation, and maintenance. The goal is to produce the maximum value with the minimum investment and cost while maintaining or enhancing longer term viability and reputation of the enterprise or the institution.

Fourth is the coordinating function of the mechanical engineer, including management, consulting, and, in some cases, marketing.

In these functions there is a long continuing trend toward the use of scientific instead of traditional or intuitive methods. Operations research, value engineering, and PABLA (problem analysis by logical approach) are typical titles of such rationalized approaches. Creativity, however, cannot be rationalized. The ability to take the important and unexpected step that opens up new solutions remains in mechanical engineering, as elsewhere, largely a personal and spontaneous characteristic.

Branches of mechanical engineering. *Development of machines for the production of goods.* The high standard of living in the developed countries owes much to mechanical engineering. The mechanical engineer invents machines to produce goods and develops machine tools of increasing accuracy and complexity to build the machines.

The principal lines of development of machinery have been an increase in the speed of operation to obtain high rates of production, improvement in accuracy to obtain quality and economy in the product, and minimization of operating costs. These three requirements have led to the evolution of complex control systems.

The most successful production machinery is that in which the mechanical design of the machine is closely integrated with the control system. A modern transfer (conveyor) line for the manufacture of automobile engines is a good example of the mechanization of a complex series of manufacturing processes. Developments are in hand to automate production machinery further, using computers to store and process the vast amount of data required for manufacturing a variety of components with a small number of versatile machine tools.

Development of machines for the production of power. The steam engine provided the first practical means of generating power from heat to augment the old sources of power from muscle, wind, and water. One of the first challenges to the new profession of mechanical engineering was to increase thermal efficiencies and power; this was done principally by the development of the steam turbine and associated large steam boilers. The 20th century has witnessed a continued rapid growth in the power output of turbines for driving electric generators, together with a steady increase in thermal efficiency and reduction in capital cost per kilowatt of large power stations. Finally, mechanical engineers acquired the resource of nuclear energy, whose application has demanded an exceptional standard of reliability and safety involving the solution of entirely new problems (see *Nuclear engineering* below).

Complex control systems

The mechanical engineer is also responsible for the much smaller internal combustion engines, both reciprocating (gasoline and diesel) and rotary (gas-turbine and Wankel) engines, with their widespread transport applications. In the transportation field generally, in air and space as well as on land and sea, the mechanical engineer has created the equipment and the power plant, collaborating increasingly with the electrical engineer, especially in the development of suitable control systems.

Development of military weapons. The skills applied to war by the mechanical engineer are similar to those required in civilian applications, though the purpose is to enhance destructive power rather than to raise creative efficiency. The demands of war have channeled huge resources into technical fields, however, and led to developments that have profound benefits in peace. Jet aircraft and nuclear reactors are notable examples.

Environmental control. The earliest efforts of mechanical engineers were aimed at controlling the human environment by draining and irrigating land and by ventilating mines. Refrigeration and air conditioning are examples of the use of modern mechanical devices to control the environment.

Many of the products of mechanical engineering, together with technological developments in other fields, give rise to noise, the pollution of water and air, and the derelection of land and scenery. The rate of production, both of goods and power, is rising so rapidly that regeneration by natural forces can no longer keep pace. A rapidly growing field for mechanical engineers and others is environmental control, comprising the development of machines and processes that will produce fewer pollutants and of new equipment and techniques that can reduce or remove the pollution already generated. (J.F.Br./P.McG.R./Ed.)

Side effects of development

CHEMICAL ENGINEERING

Chemical engineering is the development of processes and the design and operation of plants in which materials undergo changes in physical or chemical state on a technical scale. Applied throughout the process industries, it is founded on the principles of chemistry, physics, and mathematics. The laws of physical chemistry and physics govern the practicability and efficiency of chemical engineering operations. Energy changes, deriving from thermodynamic considerations, are particularly important. Mathematics is a basic tool in optimization and modeling. Optimization means arranging materials, facilities, and energy to yield as productive and economical an operation as possible. Modeling is the construction of theoretical mathematical prototypes of complex process systems, commonly with the aid of computers.

History. Chemical engineering is as old as the process industries. Its heritage dates from the fermentation and evaporation processes operated by early civilizations. Modern chemical engineering emerged with the development of large-scale, chemical-manufacturing operations in the second half of the 19th century. Throughout its development as an independent discipline, chemical engineering has been directed toward solving problems of designing and operating large plants for continuous production.

Manufacture of chemicals in the mid-19th century consisted of modest craft operations. Increase in demand, public concern at the emission of noxious effluents, and competition between rival processes provided the incentives for greater efficiency. This led to the emergence of combines with resources for larger operations and caused the transition from a craft to a science-based industry. The result was a demand for chemists with knowledge of manufacturing processes, known as industrial chemists or chemical technologists. The term chemical engineer was in general use by about 1900. Despite its emergence in traditional chemicals manufacturing, it was through its role in the development of the petroleum industry that chemical engineering became firmly established as a unique discipline. The demand for plants capable of operating physical separation processes continuously at high levels of efficiency was a challenge that could not be met by the traditional chemist or mechanical engineer.

A landmark in the development of chemical engineering was the publication in 1901 of the first textbook on the subject, by George E. Davis, a British chemical consultant. This concentrated on the design of plant items for specific operations. The notion of a processing plant encompassing a number of operations, such as mixing, evaporation, and filtration, and of these operations being essentially similar, whatever the product, led to the concept of unit operations. This was first enunciated by the American chemical engineer Arthur D. Little in 1915 and formed the basis for a classification of chemical engineering that dominated the subject for the next 40 years. The number of unit operations—the building blocks of a chemical plant—is not large. The complexity arises from the variety of conditions under which the unit operations are conducted.

First chemical engineering textbook

In the same way that a complex plant can be divided into basic unit operations, so chemical reactions involved in the process industries can be classified into certain groups, or unit processes (*e.g.*, polymerizations, esterifications, and

nitrations), having common characteristics. This classification into unit processes brought rationalization to the study of process engineering.

The unit approach suffered from the disadvantage inherent in such classifications: a restricted outlook based on existing practice. Since World War II, closer examination of the fundamental phenomena involved in the various unit operations has shown these to depend on the basic laws of mass transfer, heat transfer, and fluid flow. This has given unity to the diverse unit operations and has led to the development of chemical engineering science in its own right; as a result, many applications have been found in fields outside the traditional chemical industry.

Study of the fundamental phenomena upon which chemical engineering is based has necessitated their description in mathematical form and has led to more sophisticated mathematical techniques. The advent of digital computers has allowed laborious design calculations to be performed rapidly, opening the way to accurate optimization of industrial processes. Variations due to different parameters, such as energy source used, plant layout, and environmental factors, can be predicted accurately and quickly so that the best combination can be chosen.

Chemical engineering functions. Chemical engineers are employed in the design and development of both processes and plant items. In each case, data and predictions often have to be obtained or confirmed with pilot experiments. Plant operation and control is increasingly the sphere of the chemical engineer rather than the chemist. Chemical engineering provides an ideal background for the economic evaluation of new projects and, in the plant construction sector, for marketing.

Non-traditional employment

Branches of chemical engineering. The fundamental principles of chemical engineering underlie the operation of processes extending well beyond the boundaries of the chemical industry, and chemical engineers are employed in a range of operations outside traditional areas. Plastics, polymers, and synthetic fibres involve chemical-reaction engineering problems in their manufacture, with fluid flow and heat transfer considerations dominating their fabrication. The dyeing of a fibre is a mass-transfer problem. Pulp and paper manufacture involve considerations of fluid flow and heat transfer. While the scale and materials are different, these again are found in modern continuous production of foodstuffs. The pharmaceuticals industry presents chemical engineering problems, the solutions of which have been essential to the availability of modern drugs. The nuclear industry makes similar demands on the chemical engineer, particularly for fuel manufacture and reprocessing. Chemical engineers are involved in many sectors of the metals processing industry, which extends from steel manufacture to separation of rare metals.

Further applications of chemical engineering are found in the fuel industries. In the second half of the 20th century, considerable numbers of chemical engineers have been involved in space exploration, from the design of fuel cells to the manufacture of propellants. Looking to the future, it is probable that chemical engineering will provide the solution to at least two of the world's major problems: supply of adequate fresh water in all regions through desalination of seawater and environmental control through prevention of pollution. (C.Ha./Ed.)

ELECTRICAL AND ELECTRONICS ENGINEERING

Electrical engineering deals with the practical applications of electricity in all its forms, including those of the field of electronics. Electronics engineering is that branch of electrical engineering concerned with the uses of the electromagnetic spectrum and with the application of such electronic devices as integrated circuits, transistors, and vacuum tubes. In engineering practice, the distinction between electrical engineering and electronics is based on the comparative strength of the electric currents used. In this sense, electrical engineering is the branch dealing with "heavy current"—that is, electric light and power systems and apparatuses—whereas electronics engineering deals with such "light current" applications as wire and radio communication, the stored-program electronic computer, radar, and automatic control systems.

The distinction between the fields has become less sharp with recent technical progress. For example, in the high-voltage transmission of electric power, large arrays of electronic devices are used to convert transmission-line current at power levels in the tens of megawatts. Moreover, in the regulation and control of interconnected power systems, electronic computers are used to compute requirements much more rapidly and accurately than is possible by manual methods. (D.G.F.)

History. Electrical phenomena attracted the attention of European thinkers as early as the 17th century. Beginning as a mathematically oriented science, the field has remained primarily in that form; mathematical predication often precedes laboratory demonstration. The most noteworthy pioneers include Ludwig Wilhelm Gilbert and Georg Simon Ohm of Germany, Hans Christian Ørsted of Denmark, André-Marie Ampère of France, Alessandro Volta of Italy, Joseph Henry of the United States, and Michael Faraday of England. Electrical engineering may be said to have emerged as a discipline in 1864 when the Scottish physicist James Clerk Maxwell summarized the basic laws of electricity in mathematical form and predicted that radiation of electromagnetic energy would occur in a form that later became known as radio waves. In 1887 the German physicist Heinrich Hertz experimentally demonstrated the existence of radio waves.

Early theorists

First practical application

The first practical application of electricity was the telegraph, invented by Samuel F.B. Morse in 1837. The need for electrical engineers was not felt until some 40 years later, upon the invention of the telephone (1876) by Alexander Graham Bell and of the incandescent lamp (1878) by Thomas A. Edison. These devices and Edison's first central generating plant in New York City (1882) created a large demand for men trained to work with electricity.

The discovery of the "Edison effect," a flow of current through the vacuum of one of his lamps, was the first observation of current in space. Hendrick Antoon Lorentz of The Netherlands predicted the electron theory of electrical charge in 1895, and in 1897 J.J. Thomson of England showed that the Edison effect current was indeed caused by negatively charged particles (electrons). This led to the work of Guglielmo Marconi of Italy, Lee De Forest of the United States, and many others, which laid the foundations of radio engineering. In 1930 the term electronics was introduced to embrace radio and the industrial applications of electron tubes. Since 1947, when the transistor was invented by John Bardeen, William H. Brattain, and William B. Shockley, electronics engineering has been dominated by the applications of such solid-state electronic devices as the transistor, the semiconductor diode, and the integrated circuit. (J.D.R./D.G.F./Ed.)

Electrical and electronics engineering functions. *Research.* The functions performed by electrical and electronics engineers include (1) basic research in physics, other sciences, and applied mathematics in order to extend knowledge applicable to the field of electronics, (2) applied research based on the findings of basic research and directed at discovering new applications and principles of operation, (3) development of new materials, devices, assemblies, and systems suitable for existing or proposed product lines, (4) design of devices, equipment, and systems for manufacture, (5) field-testing of equipment and systems, (6) establishment of quality control standards to be observed in manufacture, (7) supervision of manufacture and production testing, (8) postproduction assessment of performance, maintenance, and repair, and (9) engineering management, or the direction of research, development, engineering, manufacture, and marketing and sales.

Consulting. The rapid proliferation of new discoveries, products, and markets in the electrical and electronics industries has made it difficult for workers in the field to maintain the range of skills required to manage their activities. Consulting engineers, specializing in new fields, are employed to study and recommend courses of action.

The educational background required for these functions tends to be highest in basic and applied research. In most major laboratories a doctorate in science or engineering is

required to fill leadership roles. Most positions in design, product development, and supervision of manufacture and quality control require a master's degree. In the high-technology industries typical of modern electronics, an engineering background at not less than the bachelor's level is required to assess competitive factors in sales engineering to guide marketing strategy.

Branches of electrical and electronics engineering. The largest of the specialized branches of electrical engineering, the branch concerned with the electronic computer, was introduced during World War II. The field of computer science and engineering has attracted members of several disciplines outside electronics, notably logicians, linguists, and applied mathematicians.

Another very large field is that concerned with electric light and power and their applications. Specialities within the field include the design, manufacture, and use of turbines, generators, transmission lines, transformers, motors, lighting systems, and appliances.

A third major field is that of communications, which comprises not only telegraphy and telephony but also satellite communications and the transmission of voice and data by laser signals through optical-fibre networks. The communication of digital data among computers connected by wire, microwave, and satellite circuits is now a major enterprise that has built a strong bond between computer and communications specialists.

Applications for other fields

The applications of electricity and electronics to other fields of science have expanded since World War II. Among the sciences represented are medicine, biology, oceanography, geoscience, nuclear science, laser physics, sonics and ultrasonics, and acoustics. Theoretical specialties within electronics include circuit theory, information theory, radio-wave propagation, and microwave theory.

Another important speciality concerns improvements in materials and components used in electrical and electronics engineering, such as conductive, magnetic, and insulating materials and the semiconductors used in solid-state devices. One of the most active areas is the development of new electronic devices, particularly the integrated circuits used in computers and other digital systems.

The development of electronic systems—equipment for consumers, such as radios, television sets, stereo equipment, video games, and home computers—occupies a large number of engineers. Another field is the application of computers and radio systems to automobiles, ships, and other vehicles. The field of aerospace electronic systems includes navigation aids for aircraft, automatic pilots, altimeters, and radar for traffic control, blind landing, and collision prevention. Many of these devices are also widely used in the marine services. (D.G.F./Ed.)

PETROLEUM ENGINEERING

Petroleum engineering is a specialized engineering discipline whose origins lie in both mining engineering and geology. The petroleum engineer, whose aim is to extract gaseous and liquid hydrocarbon products from the earth, is concerned with drilling, producing, processing, and transporting these products and handling all the related economic and regulatory considerations.

History. The foundations of petroleum engineering were established during the 1890s in California. There geologists were employed to correlate oil-producing zones and water zones from well to well to prevent extraneous water from entering oil-producing zones. From this came the recognition of the potential for applying technology to oil-field development. The American Institute of Mining and Metallurgical Engineers (AIME) established a Technical Committee on Petroleum in 1914. In 1957 the name of the AIME was changed to the American Institute of Mining, Metallurgical, and Petroleum Engineers.

Introduction of petroleum technology courses

Petroleum technology courses were introduced at the University of Pittsburgh, Pa., in 1910 and included courses in oil and gas law and industry practices; in 1915 the university granted the first degree in petroleum engineering. Also in 1910 the University of California at Berkeley offered its first courses in petroleum engineering and in 1915 established a four-year curriculum in petroleum engineering. After these pioneering efforts, professional programs spread throughout the United States and other countries.

From 1900 to 1920 petroleum engineering focused on drilling problems, such as establishing casing points for water shutoff, designing casing strings, and improving the mechanical operations in drilling and well pumping. In the 1920s petroleum engineers sought means to improve drilling practices and to improve well design by use of proper tubing sizes, chokes, and packers. They designed new forms of artificial lift, primarily rod pumping and gas lift, and studied the ways in which methods of production affected gas–oil ratios and rates of production. The technology of drilling fluids was advanced, and directional drilling became a common practice.

The economic crisis that resulted from abundant discoveries in about 1930, notably in the giant East Texas Field, caused petroleum engineering to focus on the entire oil–water–gas reservoir system rather than on the individual well. Studying the optimum spacing of wells in an entire field led to the concept of reservoir engineering. During this period the mechanics of drilling and production were not neglected. Drilling penetration rates increased approximately 100 percent from 1932 to 1937.

Petrophysics (determination of fluid and rock characteristics) was introduced late in the 1930s. By 1940 electric logging had developed to the state that estimates could be made of oil and water saturations in the reservoir rocks.

After World War II, petroleum engineers continued to refine the techniques of reservoir analysis and petrophysics. The outstanding event of the 1950s was development of the offshore oil industry and a whole new technology. At first little was known of such matters as wave heights and wave forces. The oceanographer and marine engineer thus joined with the petroleum engineer to initiate design standards. Shallow-water drilling barges evolved into mobile platforms, then into jack-up barges, and finally into semi-submersible and floating drilling ships.

Specialization

Branches of petroleum engineering. During the evolution of petroleum engineering, the areas of specialization developed: drilling engineering, production engineering, reservoir engineering, and petrophysical engineering. In each specialization engineers from other disciplines (mechanical, civil, electrical, geological, chemical) freely entered, and their contributions were significant; however, it remained the unique role of the petroleum engineer to integrate all the specializations into an efficient system of oil and gas drilling, production, and processing.

Drilling engineering was among the first applications of technology to oil-field practices. The drilling engineer is responsible for the design of the earth-penetration techniques, the selection of casing and safety equipment, and, often, the direction of the operations. These functions involve understanding the nature of the rocks to be penetrated, the stresses in these rocks, and the techniques available to drill into and control the underground reservoirs. Because modern drilling involves organizing a vast array of machinery and materials, investing huge funds, and acknowledging the safety and welfare of the general public, the engineer must develop the skills of supervision, management, and negotiation.

The production engineer's work begins upon completion of the well—directing the selection of producing intervals and making arrangements for various accessories, controls, and equipment. Later his work involves controlling and measuring the produced fluids (oil, gas, and water), designing and installing gathering and storage systems, and delivering the raw products (gas and oil) to pipeline companies and other transportation agents. He is also involved in such matters as corrosion prevention, well performance, and formation treatments to stimulate production. As in all branches of petroleum engineering, the production engineer cannot view the in-hole or surface processing problems in isolation but must fit solutions into the complete reservoir, well, and surface system.

Reservoir engineers are concerned with the physics of oil and gas distribution and their flow through porous rocks—the various hydrodynamic, thermodynamic, gravitational, and other forces involved in the rock–fluid system. They are responsible for analyzing the rock–fluid system, establishing efficient well-drainage patterns, forecasting the

performance of the oil or gas reservoir, and introducing methods for maximum efficient production.

To understand the reservoir rock–fluid system, the drilling, production, and reservoir engineers draw assistance from the petrophysical, or formation-evaluation, engineer, who provides tools and analytical techniques for determining rock and fluid characteristics. The petrophysical engineer measures the acoustic, radioactive, and electrical properties of the rock–fluid system and takes samples of the rocks and well fluids to determine porosity, permeability, and fluid content in the reservoir.

(B.D.H./Ed.)

AEROSPACE ENGINEERING

Aerospace engineering is the study of the design, development, and operation of vehicles operating in the Earth's atmosphere or in outer space. In 1958 the first definition of aerospace engineering appeared, considering the Earth's atmosphere and the space above it as a single realm for development of flight vehicles. Today the more encompassing aerospace definition has commonly replaced the terms aeronautical engineering and astronautical engineering.

The design of a flight vehicle demands a knowledge of many engineering disciplines. It is rare that one person takes on the entire task; instead, most companies have design teams specialized in the sciences of aerodynamics, propulsion systems, structural design, materials, avionics, and stability and control systems. No single design can optimize all of these sciences, but rather there exist compromised designs that incorporate the vehicle specifications, available technology, and economic feasibility.

History. *Aeronautical engineering.* The roots of aeronautical engineering can be traced to the early days of mechanical engineering, to inventors' concepts, and to the initial studies of aerodynamics, a branch of theoretical physics. The earliest sketches of flight vehicles were drawn by Leonardo da Vinci, who suggested two ideas for sustentation. The first was an ornithopter, a flying machine using flapping wings to imitate the flight of birds. The second idea was an aerial screw, the predecessor of the helicopter. Manned flight was first achieved in 1783, in a hot-air balloon designed by the French brothers Joseph-Michel and Jacques-Étienne Montgolfier. Aerodynamics became a factor in balloon flight when a propulsion system was considered for forward movement. Benjamin Franklin was one of the first to propose such an idea, which led to the development of the dirigible. The power-driven balloon was invented by Henri Giffard, a Frenchman, in 1852. The invention of lighter-than-air vehicles occurred independently of the development of aircraft. The breakthrough in aircraft development came in 1799 when Sir George Cayley, an English baron, drew an airplane incorporating a fixed wing for lift, an empennage (consisting of horizontal and vertical tail surfaces for stability and control), and a separate propulsion system. Because engine development was virtually nonexistent, Cayley turned to gliders, building the first successful one in 1849. Gliding flights established a data base for aerodynamics and aircraft design. Otto Lilienthal, a German scientist, recorded more than 2,000 glides in a five-year period, beginning in 1891. Lilienthal's work was followed by the American aeronaut Octave Chanute, a friend of the American brothers Orville and Wilbur Wright, the fathers of modern manned flight.

The first manned flight

Following the first sustained flight of a heavier-than-air vehicle in 1903, the Wright brothers refined their design, eventually selling airplanes to the U.S. Army. The first major impetus to aircraft development occurred during World War I, when aircraft were designed and constructed for specific military missions, including fighter attack, bombing, and reconnaissance. The end of the war marked the decline of military high-technology aircraft and the rise of civil air transportation. Many advances in the civil sector were due to technologies gained in developing military and racing aircraft. A successful military design that found many civil applications was the U.S. Navy Curtiss NC-4 flying boat, powered by four 400-horsepower V-12 Liberty engines. It was the British, however, who paved the way in civil aviation in 1920 with a 12-passenger Handley-Page transport. Aviation boomed after Charles A. Lindbergh's solo flight across the Atlantic Ocean in 1927. Advances in metallurgy led to improved strength-to-weight ratios and, coupled with a monocoque design, enabled aircraft to fly farther and faster. Hugo Junkers, a German, built the first all-metal monoplane in 1910, but the design was not accepted until 1933, when the Boeing 247-D entered service. The twin-engine design of the latter established the foundation of modern air transport.

The advent of the turbine-powered airplane dramatically changed the air transportation industry. Germany and Britain were concurrently developing the jet engine, but it was a German Heinkel He 178 that made the first jet flight on Aug. 27, 1939. Even though World War II accelerated the growth of the airplane, the jet aircraft was not introduced into service until 1944, when the British Gloster Meteor became operational, shortly followed by the German Me 262. The first practical American jet was the Lockheed F-80, which entered service in 1945.

Commercial aircraft after World War II continued to use the more economical propeller method of propulsion. The efficiency of the jet engine was increased, and in 1949 the British de Havilland Comet inaugurated commercial jet transport flight. The Comet, however, experienced structural failures that curtailed the service, and it was not until 1958 that the highly successful Boeing 707 jet transport began nonstop transatlantic flights. While civil aircraft designs utilize most new technological advancements, the transport and general aviation configurations have changed only slightly since 1960. Because of escalating fuel and hardware prices, the development of civil aircraft has been dominated by the need for economical operation.

Technological improvements in propulsion, materials, avionics, and stability and controls have enabled aircraft to grow in size, carrying more cargo faster and over longer distances. While aircraft are becoming safer and more efficient, they are also now very complex. Today's commercial aircraft are among the most sophisticated engineering achievements of the day.

Growing complexity of aircraft

Smaller, more fuel-efficient airliners are being developed. The use of turbine engines in light general aviation and commuter aircraft is being explored, along with more efficient propulsion systems, such as the propfan concept. Using satellite communication signals, onboard microcomputers can provide more accurate vehicle navigation and collision-avoidance systems. Digital electronics coupled with servo mechanisms can increase efficiency by providing active stability augmentation of control systems. New composite materials providing greater weight reduction; inexpensive one-man, lightweight, noncertified aircraft, referred to as ultralights; and alternate fuels such as ethanol, methanol, synthetic fuel from shale deposits and coal, and liquid hydrogen are all being explored. Aircraft designed for vertical and short takeoff and landing, which can land on runways one-tenth the normal length, are being developed. Hybrid vehicles such as the Bell XV-15 tilt-rotor already combine the vertical and hover capabilities of the helicopter with the speed and efficiency of the airplane. Although environmental restrictions and high operating costs have limited the success of the supersonic civil transport, the appeal of reduced traveling time justifies the examination of a second generation of supersonic aircraft.

Aerospace engineering. The use of rocket engines for aircraft propulsion opened a new realm of flight to the aeronautical engineer. Robert H. Goddard, an American, developed, built, and flew the first successful liquid-propellant rocket on March 16, 1926. Goddard proved that flight was possible at speeds greater than the speed of sound and that rockets can work in a vacuum. The major impetus in rocket development came in 1938 when the American James Hart Wyld designed, built, and tested the first U.S. regeneratively cooled liquid rocket engine. In 1947 Wyld's rocket engine powered the first supersonic research aircraft, the Bell X-1, flown by the U.S. Air Force captain Charles E. Yeager. Supersonic flight offered the aeronautical engineer new challenges in propulsion, structures and materials, high-speed aeroelasticity, and transonic, supersonic, and hypersonic aerodynamics. The

experience gained in the X-1 tests led to the development of the X-15 research rocket plane, which flew more than 700 flights over a 22-year period. The X-15 established an extensive database in transonic and supersonic flight (up to five times the speed of sound) and revealed vital information concerning the upper atmosphere.

Space exploration

The late 1950s and '60s marked a period of intense growth for astronautical engineering. In 1957 the U.S.S.R. orbited Sputnik I, the world's first artificial satellite, which triggered a space exploration race with the United States. In 1961 U.S. president John F. Kennedy recommended to Congress to undertake the challenge of "landing a man on the Moon and returning him safely to the Earth" by the end of the 1960s. This commitment was fulfilled on July 20, 1969, when astronauts Neil A. Armstrong and Edwin E. Aldrin, Jr., landed on the Moon.

The 1970s began the decline of the U.S. manned spaceflights. The exploration of the Moon was replaced by unmanned voyages to Jupiter, Saturn, and other planets. The exploitation of space was redirected from conquering distant planets to providing a better understanding of the human environment. Artificial satellites provide data pertaining to geographic formations, oceanic and atmospheric movements, and worldwide communications. The frequency of U.S. spaceflights in the 1960s and '70s led to the development of a reusable, low-orbital-altitude space shuttle. Known officially as the Space Transportation System, the shuttle has made numerous flights since its initial launch on April 12, 1981. It has been used for both military and commercial purposes (*e.g.,* deployment of communications satellites).

Aerospace engineering functions. In most countries, governments are the aerospace industry's largest customers, and most engineers work on the design of military vehicles. The largest demand for aerospace engineers comes from the transport and fighter aircraft, missile, spacecraft, and general aviation industries. The typical aerospace engineer holds a bachelor's degree, but there are many engineers holding master's or doctorate degrees (or their equivalents) in various disciplines associated with aerospace-vehicle design, development, and testing.

The U.S. National Aeronautics and Space Administration (NASA) is a governmental organization that employs many engineers for research, development, testing, and procurement of military vehicles. Government agencies award and monitor industrial contracts ranging from engineering problem studies to design and fabrication of hardware. Universities receive limited funding, primarily for analytical research. Some of the larger institutions, however, are developing or expanding flight-research facilities and increasing faculty members in an effort to increase productivity in both research and testing.

The design of a flight vehicle is a complex and time-consuming procedure requiring the integration of many engineering technologies. Supporting teams are formed to provide expertise in these technologies, resulting in a completed design that is the best compromise of all the engineering disciplines. Usually the support teams are supervised by a project engineer or chief designer for technical guidance and by a program manager responsible for program budgets and schedules. Because of the ever-increasing requirement for advanced technology and the high cost and high risk associated with complex flight vehicles, many research and development programs are canceled before completion.

The phases of the design process

The design process can be dissected into five phases and is the same for most aerospace products. Phase one is a marketing analysis to determine customer specifications or requirements. Aerospace engineers are employed to examine technical, operational, or financial problems. The customer's requirements are established and then passed on to the conceptual design team for the second phase.

The conceptual design team generally consists of aerospace engineers, who make the first sketch attempt to determine the vehicle's size and configuration. Preliminary estimates of the vehicle's performance, weight, and propulsion systems are made. Performance parameters include range, speed, drag, power required, payload, and takeoff and landing distances. Parametric trade studies are conducted to optimize the design, but configuration details usually change. This phase may take from a few months to years for major projects.

Phase three is the preliminary design phase. The optimized vehicle design from phase two is used as the starting point. Aerospace engineers perform computer analyses on the configuration; then wind-tunnel models are built and tested. Flight control engineers study dynamic stability and control problems. Propulsion groups supply data necessary for engine selection. Interactions between the engine inlet and vehicle frame are studied. Civil, mechanical, and aerospace engineers analyze the bending loads, stresses, and deflections on the wing, airframe, and other components. Material science engineers aid in selecting low-weight, high-strength materials and may conduct aeroelastic and fatigue tests. Weight engineers make detailed estimates of individual component weights. As certain parameters drive the vehicle design, the preliminary designers are often in close contact with both the conceptual designers and the marketing analysts. The time involved in the preliminary design phase depends on the complexity of the problem but usually takes from six to 24 months.

Phase four, the detailed design phase, involves construction of a prototype. Mechanical engineers, technicians, and draftsmen help lay out the drawings necessary to construct each component. Full-scale mock-ups are built of cardboard, wood, or other inexpensive materials to aid in the subsystem layout. Subsystem components are built and bench-tested, and additional wind-tunnel testing is performed. This phase takes from one to three years.

The final phase concerns flight-testing the prototype. Engineers and test pilots work together to assure that the vehicle is safe and performs as expected. If the prototype is a commercial transport aircraft, the vehicle must meet the requirements specified by government organizations such as the Federal Aviation Administration in the United States and the Civil Aviation Authority in the United Kingdom. Prototype testing is usually completed in one year but can take much longer because of unforeseen contingencies. The time required from the perception of a customer's needs to delivery of the product can be as long as 10 to 15 years depending on the complexity of the design, the political climate, and the availability of funding.

High-speed computers have now enabled complex aerospace engineering problems to be analyzed rapidly. More extensive computer programs, many written by aerospace engineers, are being formulated to aid the engineer in designing new configurations.

Branches of aerospace engineering. The aerospace engineer is armed with an extensive background suitable for employment in most positions traditionally occupied by mechanical engineers as well as limited positions in the other various engineering disciplines. The transportation, construction, communication, and energy industries provide the most opportunities for non-aerospace applications.

Non-aerospace applications

Because land and sea vehicles are designed for optimum speed and efficiency, the aerospace engineer has become a prominent member of the design teams. Because up to half of the power required to propel a vehicle is due to the resistance of the air, the configuration design of low-drag automobiles, trains, and boats offers better speed and fuel economy. The presence of the aerospace engineer in the automobile industry is evident from the streamlined shapes of cars and trucks that evolved during the late 20th century, at a time when gasoline prices were escalating and the aerospace industry was in a lull. Airline companies employ engineers as performance analysts, crash investigators, and consultants. The Federal Aviation Administration makes use of the technical expertise of the aerospace engineer in various capacities.

The construction of large towers, buildings, and bridges requires predictions of aerodynamic forces and the creation of an optimum design to minimize these forces. The consideration of aerodynamic forces of flat surfaces such as the side of a building or superstructure is not new. In 1910 Alexandre-Gustave Eiffel achieved remarkable experimental results measuring the wind resistance of a flat plate, using the Eiffel Tower as a test platform.

Many companies benefit not from the advanced hard-

ware developments of aerospace technology but by the understanding and application of aerospace methodology. Companies engaged in satellite communications require an understanding of orbital mechanics, trajectories, acceleration forces, and aerodynamic heating and an overall knowledge of the spacecraft industry. Advanced aerodynamic design of airfoils and rotor systems is applied in an effort to improve the efficiency of propellers, windmills, and turbine engines. The impact of aerospace technology has trickled down to many companies engaged in the research and development of flight simulation, automatic controls, materials, dynamics, robotics, medicine, and other high-technology fields. (K.A.St./Ed.)

BIOENGINEERING

Bioengineering is the application of engineering knowledge to the fields of medicine and biology. The bioengineer must be well grounded in biology and have engineering knowledge that is broad, drawing upon electrical, chemical, mechanical, and other engineering disciplines. The bioengineer may work in any of a large range of areas. One of these is the provision of artificial means to assist defective body functions—such as hearing aids, artificial limbs, and supportive or substitute organs. In another direction, the bioengineer may use engineering methods to achieve biosynthesis of animal or plant products—such as for fermentation processes.

History. Before World War II the field of bioengineering was essentially unknown, and little communication or interaction existed between the engineer and the life scientist. A few exceptions, however, should be noted. The agricultural engineer and the chemical engineer, involved in fermentation processes, have always been bioengineers in the broadest sense of the definition since they deal with biological systems and work with biologists. The civil engineer, specializing in sanitation, has applied biological principles in the work. Mechanical engineers have worked with the medical profession for many years in the development of artificial limbs. Another area of mechanical engineering that falls in the field of bioengineering is the air-conditioning field. In the early 1920s engineers and physiologists were employed by the American Society of Heating and Ventilating Engineers to study the effects of temperature and humidity on humans and to provide design criteria for heating and air-conditioning systems.

Today there are many more examples of interaction between biology and engineering, particularly in the medical and life-support fields. In addition to an increased awareness of the need for communication between the engineer and the associate in the life sciences, there is an increasing recognition of the role the engineer can play in several of the biological fields, including human medicine, and, likewise, an awareness of the contributions biological science can make toward the solution of engineering problems.

Much of the increase in bioengineering activity can be credited to electrical engineers. In the 1950s bioengineering meetings were dominated by sessions devoted to medical electronics. Medical instrumentation and medical electronics continue to be major areas of interest, but biological modeling, blood-flow dynamics, prosthetics, biomechanics (dynamics of body motion and strength of materials), biological heat transfer, biomaterials, and other areas are now included in conference programs.

The merging of medical and engineering needs

Bioengineering developed out of specific desires or needs: the desire of surgeons to bypass the heart, the need for replacement organs, the requirement for life support in space, and many more. In most cases the early interaction and education were a result of personal contacts between physician, or physiologist, and engineer. Communication between the engineer and the life scientist was immediately recognized as a problem. Most engineers who wandered into the field in its early days probably had an exposure to biology through a high-school course and no further work. To overcome this problem, engineers began to study not only the subject matter but also the methods and techniques of their counterparts in medicine, physiology, psychology, and biology. Much of the information was self-taught or obtained through personal association and discussions. Finally, recognizing a need to assist in overcoming the communication barrier as well as to prepare engineers for the future, engineering schools developed courses and curricula in bioengineering.

Branches of bioengineering. *Medical engineering.* Medical engineering concerns the application of engineering principles to medical problems, including the replacement of damaged organs, instrumentation, and the systems of health care, including diagnostic applications of computers.

Agricultural engineering. This includes the application of engineering principles to the problems of biological production and to the external operations and environment that influence this production.

Bionics. Bionics is the study of living systems so that the knowledge gained can be applied to the design of physical systems.

Biochemical engineering. Biochemical engineering includes fermentation engineering, application of engineering principles to microscopic biological systems that are used to create new products by synthesis, including the production of protein from suitable raw materials.

Human-factors engineering. This concerns the application of engineering, physiology, and psychology to the optimization of the human–machine relationship.

Environmental health engineering. Also called bioenvironmental engineering, this field concerns the application of engineering principles to the control of the environment for the health, comfort, and safety of human beings. It includes the field of life-support systems for the exploration of outer space and the ocean. (Ed.)

NUCLEAR ENGINEERING

Nuclear engineering is concerned with the control and use of energy and radiation released from nuclear reactions. It encompasses the development, design, and construction of power reactors, naval-propulsion reactors, nuclear fuel-cycle facilities, and radioactive-waste disposal facilities; the development and production of nuclear weapons; and the production and application of radioisotopes.

History. Nuclear engineering began with the first major demonstrations of the utilization of nuclear energy: the development of nuclear weapons and nuclear reactors.

The Manhattan Project

The World War II Manhattan Project, under which the U.S. government built, in a relatively short period, such facilities as production reactors, chemical-reprocessing plants, test and research reactors, and weapons production facilities, stands out as a monumental engineering feat. Engineers in early programs had to learn about a host of nuclear-related subjects, ranging from reactor theory and reactor control to radioactivity and the behaviour of material under irradiation. They were educated on the job by nuclear scientists and physicists, first through personal discussions and later through seminars and classes. Many of those who entered the field had been educated in other engineering disciplines—mechanical, electrical, chemical, and so on. Nuclear engineering continues today to be a strongly interdisciplinary activity.

Early schools. In the late 1940s, as the many potential peaceful uses of nuclear energy became evident, two schools of reactor technology were established, one in Tennessee at Oak Ridge National Laboratory and another in Illinois at Argonne National Laboratory.

In 1946 Clinch College was established at Oak Ridge. In its first year 35 American participants from universities, industry, the U.S. Navy, and government agencies took courses in nuclear technology. They attended lectures, conducted laboratory experiments, and gained hands-on experience in operating nuclear reactors.

In 1950 Clinch College was succeeded by the Oak Ridge School of Reactor Technology (ORSORT). The participants were again selected from academic, government, and industry sectors. In addition to lectures and laboratory work, the students were assigned to teams working on the development of new concepts. Several concepts developed by these teams later grew into major research and development programs, including the high-flux isotope reactor, the molten-salt reactor, and several nuclear propulsion schemes. ORSORT was disbanded in 1965 because nuclear engineering programs had by that time become widely available at universities and colleges.

The International School of Nuclear Science and Engineering was established at Argonne National Laboratory in 1955. The school was created to meet the international need for trained scientists and engineers, and its program was conducted jointly by Argonne National Laboratory, North Carolina State College, and Pennsylvania State University. Basic course work was presented at the universities in a 17-week program combining lecture with laboratory experience. More advanced work, including lectures and participation in design and laboratory projects, was given in a second 17-week program at the International School at Argonne. In 1960 the basic course work was discontinued, and the program was redirected to serve more advanced and experienced students from abroad. In recognition of the worldwide growth of programs and facilities to provide basic nuclear training at universities and laboratories, the program at Argonne was discontinued in 1964.

University programs. In 1950 the first full-fledged nuclear engineering curriculum offered for college credit was established at North Carolina State College. By 1952 several schools had graduate programs in nuclear engineering. Most of these programs consisted of two or three courses, providing a background on reactor physics, reactor control, heat transfer, radiation effects, and shielding.

With the support of the U.S. Atomic Energy Commission's Division of Nuclear Education and Training, the curricula and the number of schools in the United States continued to increase. By 1965, 61 schools were offering nuclear engineering programs. The programs had grown in diverse directions, however, and it became apparent that it was desirable to develop a consensus among educators about nuclear engineering education. To meet this need, a joint committee of the American Nuclear Society and the American Society of Engineering Education developed basic educational criteria. The committee members came from industry, national laboratories, and universities with nuclear engineering programs. The committee's "Report on Objective Criteria in Nuclear Engineering Education" had a major influence in shaping nuclear engineering curricula around the world and did much to establish nuclear engineering as a distinct discipline.

Education criteria established

Nuclear engineering functions. *Research and development.* Research and development entails the conception and development of new materials, processes, components, and systems for nuclear facilities and the development of analytical methods and experimental procedures for use in the development, analysis, design, and control of fission and fusion systems.

Design. Another area of emphasis is the engineering design of such items as fuel elements, reactor-core supports, reflectors, thermal shields, biological shields, instrumentation and control systems, and safety systems.

Fuel management. Fuel management involves specifying, procuring, and managing fuel throughout its reactor lifetime and beyond.

Safety analysis. Normal and anticipated abnormal operating conditions must be considered in the analysis of the safety of a reactor or other facility using radioactive material. Hypothetical reactor accidents are analyzed to assess possible consequences and to devise means to prevent or mitigate these consequences.

Operation and test. This function of nuclear engineering is concerned with the supervision and operation of nuclear power reactors and ancillary nuclear facilities.

Affected industries

Nuclear engineers perform these functions for various kinds of employers: (1) architectural engineering firms, in which they handle design, safety analysis, project coordination, construction supervision, quality assurance, quality control, and related matters, (2) reactor vendors and other manufacturing organizations, in which they pursue research, development, design, manufacture, and installation of various components of nuclear systems, (3) electric utility companies, in which they handle planning, construction supervision, reactor-safety analysis, in-core nuclear fuel management, power-reactor economic analysis, environmental-impact assessment, personnel training, plant management, operation-shift supervision, radiation protection, spent-fuel storage, and radioactive-waste management, (4) regulatory agencies, in which they undertake licensing, rule making, safety research, risk analysis, on-site inspection, and research administration, (5) defense programs, in which they are employed in naval and nuclear weapons programs, (6) universities, in which they hold various faculty positions, and (7) national laboratories and industrial research laboratories, in which they carry out advanced research and development on a variety of nuclear programs in nuclear energy areas. Most of the advanced research and development on nuclear-related programs is conducted at national laboratories.

Branches of nuclear engineering. *Nuclear power.* The greatest growth in the nuclear industry has been in the development of nuclear power plants. It is estimated that by the year 2000 one-third of all electric power generated worldwide will come from nuclear power plants.

Nearly all commercial nuclear reactors in operation or under construction are thermal reactors. They are called thermal reactors because their fuel is fissioned by neutrons that have been slowed down by a moderator until they are in thermal equilibrium with the moderator. The boiling water reactor (BWR) and the pressurized water reactor (PWR) are the two predominant types of power reactors in use throughout the world. Both types are called light-water reactors (LWR). The water is used in these reactors as both moderator and coolant. In the BWR, steam is generated by direct boiling of water in the reactor core. In the PWR, steam is produced in an external steam generator rather than in the core, where the coolant under pressure is not allowed to boil. Other types of power reactors include graphite-moderated gas-cooled reactors in use in Great Britain and pressurized heavy-water reactors in Canada.

A major advance in nuclear power is expected with the further development of the liquid-metal fast-breeder reactor (LMFBR). Programs are in progress in several countries to develop and deploy the LMFBR. (The reactor is cooled by a liquid metal, sodium, and fission is caused by fast neutrons. The reactor is called a breeder because it produces more nuclear fuel than it consumes.) Fuel in the breeder is utilized 60 times more effectively than that in light-water reactors. It is estimated that without the breeder the world supply of fissionable material for nuclear power plants could be consumed in a few decades. With the improved fuel utilization provided by the breeder, nuclear power plants would be able to supply the world's electric energy requirement for centuries.

Fusion. Fusion is a potential energy resource with a wide range of applications. The fusion process of combining two light atoms to form a heavier atom, with less mass than the two original atoms, is the basic energy process in the universe (*i.e.,* fusion is the process that takes place in all stars). If fusion can be harnessed for terrestrial applications, the energy can be released in a variety of forms, including charged particles, electromagnetic radiation, and neutrons. Possible applications include electricity production, synthetic fuel production, process-heat applications, and fissile fuel production for fission reactors.

Plasma physics

Fusion research since about 1950 has concentrated on the issues of plasma physics, specifically the production of high-temperature plasmas (100,000,000° C [180,000,000° F] or greater) that can be confined at sufficiently high densities for sufficiently long times to produce net energy. Energy break-even conditions are expected to be demonstrated in several fusion devices in the late 20th century. Fusion physics research has made steady progress, and research efforts have begun to address the important engineering issues of fusion. Among the more important of these issues are those related to extracting useful energy from a plasma and developing complete fuel systems for fusion reactors. These areas are expected to receive increased research and development support in the future.

Naval nuclear propulsion. The use of nuclear reactors to propel naval vessels has revolutionized naval operations throughout the world. The navies of Great Britain, France, China, the United States, Russia, and Ukraine are equipped with nuclear-powered ships, which are considered to be essential to the defense of their countries. Nuclear warships are capable of nearly unlimited high-speed operation without the need of fuel-oil support. In the 25 years following the maiden voyage of the *Nautilus* in

1954, the nuclear navy of the United States steamed more than 80,000,000 kilometres (50,000,000 miles) throughout the oceans of the world, accumulating 25 centuries of reactor plant operation without any accidents involving a nuclear reactor. By the mid-1980s more than 40 percent of U.S. combat warships were nuclear-powered.

Nuclear weapons. Fission weapons (atomic bombs), fusion weapons (hydrogen bombs), and combination fission-fusion weapons are part of the world's nuclear arsenal. Nuclear engineers are employed on weapons programs in such diverse activities as research, development, design, fabrication, production, testing, maintenance, and surveillance of a large array of nuclear weapons systems.

Efforts are in progress in the United States to develop, upgrade, and integrate weapons into warhead programs and to explore advanced concepts for future weapons systems. A concept of particular interest is inertial-confinement fusion. This program is directed at determining the feasibility of burning very small pellets of thermonuclear fuel using laser or particle-beam drivers. The program is of interest not only for applications to weapons physics but also for possible energy applications.

Radioisotopes. More than 500 radioisotopes are produced in nuclear reactors. The production, packaging, and application of these isotopes has become a large industry. They are used in heart pacemakers, medical research, sterilization of medical instruments, industrial tracers, X-ray equipment, curing of plastics, preservation of food, and as an energy source in electric generators. Perhaps the most important use of radioisotopes is in the field of medicine. They are used in procedures for half of all patients admitted to hospitals in the United States.

Nuclear-waste management. Nuclear wastes can be classified in two groups, low-level and high-level. Low-level wastes come from nuclear power facilities, hospitals, and research institutions and include such items as contaminated clothing, wiping rags, tools, test tubes, needles, and other medical research materials. In the disposal of low-level wastes, the wastes are reduced in volume, then packaged in leak-proof containers, which are placed in an earth-covered trench in a low-level-waste disposal site. Such sites should be continuously monitored to detect any migration of radioactive material. High-level wastes are highly radioactive and derive from the chemical reprocessing of spent fuel elements and from the weapons program.

By the late 20th century many countries were evaluating potential nuclear-waste disposal sites and developing terminal waste-storage technology. All these countries were preparing to handle high-level wastes. All had identified geologic formations that appeared to be technically feasible for repositories. In 1982 the U.S. Congress passed legislation establishing schedules for the selection, development, licensing, and construction of repositories for the safe, permanent storage of high-level waste. (I.Bo./Ed.)

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English Literature

Although for the purposes of this article English literature is treated as being confined to writings in English by natives or inhabitants of the British Isles (including Ireland), it is to a certain extent the case that literature—and this is particularly true of the literature written in English—knows no frontiers. Thus, English literature can be regarded as a cultural whole of which the mainstream literatures of the United States, Australia, New Zealand, and Canada and important elements in the literatures of other Commonwealth or ex-Commonwealth countries are parts (see AMERICAN LITERATURE; AUSTRALIA AND NEW ZEALAND, LITERATURES OF; and CANADIAN LITERATURE).

English literature has sometimes been stigmatized as insular. It can be argued that no single English novel attains the universality of the Russian writer Leo Tolstoy's *War and Peace* or the French writer Gustave Flaubert's *Madame Bovary*. Yet in the Middle Ages the Old English literature of the subjugated Saxons was leavened by the Latin and Anglo-Norman French writings, eminently foreign in origin, in which the churchmen and the Norman conquerors expressed themselves. From this combination emerged a flexible and subtle linguistic instrument exploited by Geoffrey Chaucer and brought to supreme application by William Shakespeare. During the Renaissance the renewed interest in classical learning and values had an important effect on English literature, as on all of the arts; and ideas of Augustan literary propriety in the 18th century and reverence in the 19th century for a less specific, though still selectively viewed, classical antiquity continued to shape the literature. All three of these impulses derived from a foreign source, namely the Mediterranean basin. The Decadents of the late 19th century and modernists of the early 20th looked to continental European individuals and movements for inspiration. Nor was attraction toward European intellectualism dead in the late 20th century, for by the mid-1980s the approach known as structuralism, a phenomenon predominantly French and German in origin, infused the very study of English literature itself in a host of published critical studies and university departments.

Further, Britain's past imperial glories around the globe, particularly those that were connected with the Indian subcontinent, continued to inspire literature—in some cases wistful, in other cases hostile. Finally, English literature has enjoyed a certain diffusion abroad, not only in predominantly English-speaking countries but also in all those others where English is the first choice of study as a second language.

English literature is therefore not so much insular as detached from the continental European tradition across the Channel. It is strong in all the conventional categories of the bookseller's list: in Shakespeare it has a dramatist of world renown; in poetry, a genre notoriously resistant to adequate translation and therefore difficult to compare with the poetry of other literatures, it is so peculiarly rich as to merit inclusion in the front rank; English literature's humour has been found as hard to convey to foreigners as poetry, if not more so—a fact at any rate permitting bestowal of the label "idiosyncratic"; English literature's remarkable body of travel writings constitutes another counterthrust to the charge of insularity; in autobiography, biography, and historical writing English literature compares with the best of any culture; and children's literature, fantasy, essays, and journals, which tend to be considered minor genres, are all fields of exceptional achievement as regards English literature. Even in philosophical writings, popularly thought of as hard to combine with literary value, thinkers such as Thomas Hobbes, John Locke, David Hume, John Stuart Mill, and Bertrand Russell stand comparison for lucidity and grace with the best of the French philosophers and the masters of classical antiquity.

Some of English literature's most distinguished practitioners in the 20th century—from Henry James and Joseph Conrad at its beginning to V.S. Naipaul and Tom Stoppard more recently—were of foreign origin. What is more, none of the aforementioned had as much in common with his adoptive country as did, for instance, Doris Lessing and Peter Porter (two other distinguished writer-immigrants to Britain) by virtue both of having been born into a British family and of having been brought up on British Commonwealth soil.

On the other hand, during the same period in the 20th century, many notable practitioners of English literature left Britain to live abroad: James Joyce, D.H. Lawrence, Aldous Huxley, Christopher Isherwood, Robert Graves, Graham Greene, Muriel Spark, Anthony Burgess, and Sir Angus Wilson. In one case, that of Samuel Beckett, this process was carried to the extent of writing works first in French and then translating them into English.

Even English literature considered purely as a product of the British Isles is extraordinarily heterogeneous, however. Literature actually written in those Celtic tongues once prevalent in Cornwall, Ireland, Scotland, and Wales—called the "Celtic Fringe"—is treated separately (see CELTIC LITERATURE). Yet Irish, Scots, and Welsh writers have contributed enormously to English literature even when they have written in dialect, as the 18th-century poet Robert Burns and the 20th-century Scots writer Alasdair Gray have done. In the latter half of the 20th century interest began also to focus on writings in English or English dialect by recent settlers in Britain, such as Afro-Caribbeans and people from Africa proper, the Indian subcontinent, and East Asia.

Even within England, culturally and historically the dominant partner in the union of territories comprising Britain, literature has been as enriched by strongly provincial writers as by metropolitan ones. Another contrast more fruitful than not for English letters has been that between social milieus, however much observers of Britain in their own writings may have deplored the survival of class distinctions. As far back as medieval times a courtly tradition in literature cross-fertilized with an earthier demotic one. Shakespeare's frequent juxtaposition of royalty in one scene with plebeians in the next reflects a very British way of looking at society. This awareness of differences between high life and low, a state of affairs fertile in creative tensions, is observable throughout the history of English literature.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, Part Six, Division II, Section 621. (Ed.)

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The Old English period

POETRY

The Angles, Saxons, and Jutes who invaded Britain in the 5th and 6th centuries brought with them the common Germanic metre; but of their earliest oral poetry, probably used for panegyric, magic, and short narrative, little or none survives. For nearly a century after the conversion of King Aethelberht I of Kent to Christianity in 597, there is no evidence that the English wrote poetry in their own language. But St. Bede the Venerable, in his *Historia ecclesiastica gentis Anglorum* ("Ecclesiastical History of the English People"), wrote that in the late 7th century Caedmon, an illiterate Northumbrian cowherd, was inspired in a dream to compose a short hymn in praise of the creation. Caedmon later composed verses based on Scripture, which was expounded for him by monks at Streaneshalch (Whitby), but only the "Hymn of Creation" survives. Caedmon legitimized the native verse form by adapting it to Christian themes. Others, following his example, gave England a body of vernacular poetry unparalleled in Europe before the end of the 1st millennium.

Bede's account of Caedmon

Alliterative verse. Virtually all Old English poetry is written in a single metre, a four-stress line with a syntactical break, or caesura, between the second and third stresses, and with alliteration linking the two halves of the line; this pattern is occasionally varied by six-stress lines. The poetry is formulaic, drawing on a common set of stock phrases and phrase patterns, applying standard epithets to various classes of characters, and depicting scenery with such recurring images as the eagle and wolf, which wait during battles to feast on carrion, and the ice and snow, which appear in the landscape to signal sorrow. In the best poems such formulas, far from being tedious, give a strong impression of the richness of the cultural fund from which poets could draw. Other standard devices of this poetry are the kenning, a metaphorical name for a thing, usually expressed in a compound noun (*e.g.*, "swan-road" used to name the sea); and variation, the repeating of a single idea in different words, with each repetition adding a new level of meaning. That these verse techniques changed little during 400 years of literary production suggests the extreme conservatism of Anglo-Saxon culture.

The major manuscripts. Most Old English poetry is preserved in four manuscripts of the late 10th and early 11th centuries. The Beowulf manuscript (British Library) contains *Beowulf, Judith,* and three prose tracts; the Exeter Book (Exeter cathedral) is a miscellaneous gathering of lyrics, riddles, didactic poems, and religious narratives; the Junius manuscript (Bodleian Library, Oxford) contains biblical paraphrases; and the Vercelli Book (cathedral library, Vercelli, Italy) contains saints' lives, several short religious poems, and prose homilies. In addition to the poems in these books are historical poems in the *Anglo-Saxon Chronicle;* poetic renderings of Psalms 51–150; the 31 "Metres" included in King Alfred the Great's translation of Boethius' *Consolation of Philosophy;* magical, didactic, elegiac, and heroic poems; and others, miscellaneously interspersed with prose, jotted in margins and even worked in stone or metal.

Problems of dating. Few poems can be dated as closely as Caedmon's "Hymn." King Alfred's compositions fall into the late 9th century, and Bede composed his "Death Song" within 50 days of his death on May 25, 735. His-

torical poems like "The Battle of Brunanburh" (after 937) and "The Battle of Maldon" (after 991) are fixed by the dates of the events they commemorate. A translation of one of Aldhelm's riddles is found not only in the Exeter Book but also in an early 9th-century manuscript at Leiden; it can be no later than the Leiden manuscript. And at least a part of "The Dream of the Rood" can be dated by an excerpt carved on the 8th-century Ruthwell Cross (in Dumfriesshire, Scotland). But in the absence of such indications, Old English poems are hard to date, and the scholarly consensus that most were composed in the Midlands and the North in the 8th and 9th centuries has crumbled in recent years. Many now hold that "The Wanderer," *Beowulf,* and other poems once assumed to be early are of the 9th or 10th century. For most poems, little more than that they were written between the 8th and the 11th centuries can be said with certainty.

Religious verse. If few poems can be dated accurately, still fewer can be attributed to particular poets. The most important author from whom a considerable body of work survives is Cynewulf, who wove his runic signature into the epilogues of four poems. Aside from his name, little is known of him; he probably lived in the 9th century in Mercia. His works include *The Fates of the Apostles,* a short martyrology; *The Ascension* (also called *Christ II*), a homily and biblical narrative; *Juliana,* a saint's passion set in the reign of Maximian (late 3rd century AD); and *Elene,* perhaps the best of his poems, which describes the mission of St. Helena, mother of the emperor Constantine, to recover Christ's cross. Cynewulf's work is lucid and technically elegant; his theme is the continuing evangelical mission from the time of Christ to the triumph of Christianity under Constantine. Several poems not by Cynewulf are associated with him because of their subject matter. These include two lives of St. Guthlac and *Andreas,* the story of St. Andrew among the Mermedonians, which has stylistic affinities with *Beowulf.* Also in the "Cynewulf group" are several poems with Christ as their subject, of which the most important is "The Dream of the Rood," in which the cross speaks of itself as Christ's loyal thane and yet the instrument of his death. This tragic paradox echoes a recurring theme of secular poetry and at the same time movingly expresses the religious paradoxes of Christ's triumph in death and mankind's redemption from sin.

Cynewulf's poems

The Old Testament narratives (*Genesis, Exodus,* and *Daniel*) of the Junius manuscript were once attributed to Caedmon but now are thought to be of anonymous authorship. Of these *Exodus* is remarkable for its intricate diction and bold imagery. The fragmentary *Judith* of the Beowulf manuscript stirringly embellishes the story from the apocrypha of the heroine who led the Jews to victory over the Assyrians.

Elegiac and heroic verse. The term elegy is used of Old English poems that lament the loss of worldly goods, glory, or human companionship. "The Wanderer" is narrated by a man, deprived of lord and kinsmen, whose journeys lead him to the realization that there is stability only in heaven. "The Seafarer" is similar, but its journey motif more explicitly symbolizes the speaker's spiritual yearnings. Several others have similar themes, and three elegies, "The Husband's Message," "The Wife's Lament," and "Wulf and Eadwacer," describe what appears to be a conventional situation: the separation of husband and wife by the husband's exile.

"Deor" bridges the gap between the elegy and the heroic poem, for in it a poet laments the loss of his position at court by alluding to sorrowful stories from Germanic legend. *Beowulf* itself narrates the battles of Beowulf, a prince of the Geats (a tribe in what is now southern Sweden), against the monstrous Grendel, Grendel's mother, and a fire-breathing dragon. The account contains some of the best elegiac verse in the language; and by setting marvelous tales against a historical background in which victory is always temporary and strife is always renewed, the poet gives the whole an elegiac cast. *Beowulf* also is one of the best religious poems, not only because of its explicitly Christian passages but also because Beowulf's monstrous foes are depicted as God's enemies and Beowulf himself as God's champion. Other heroic narratives are fragmentary. Of "The Battle of Finnsburh" and "Waldere" only enough remains to indicate that when whole they must have been fast paced and stirring.

Beowulf

Of several poems dealing with English history and preserved in the *Anglo-Saxon Chronicle,* the most notable is "The Battle of Brunanburh," a panegyric on the occasion of King Athelstan's victory over a coalition of Norsemen and Scots in the year 937. But the best historical poem is not from the *Chronicle.* "The Battle of Maldon," which describes the defeat of Aldorman Byrhtnoth at the hands of Viking invaders in 991, states eloquently the heroic ideal, contrasting the determination of some of Byrhtnoth's thanes to avenge his death or die in the attempt with the cowardice of others who left the field. Minor poetic genres include catalogs (two sets of "Maxims" and "Widsith," a list of rulers, tribes, and notables in the heroic age), dialogues, metrical prefaces and epilogues to prose works of the Alfredian period, and liturgical poems associated with the Benedictine Office.

PROSE

The earliest English prose work, the law code of King Aethelberht I of Kent, was written within a few years of St. Augustine of Canterbury's arrival in England (597). Other 7th- and 8th-century prose, similarly practical in character, includes more laws, wills, and charters. According to Cuthbert, who was a monk at Jarrow, Bede had just finished a translation of the Gospel of St. John at the time of his death, though this does not survive; and two medical tracts, a *Herbarium* and *Medicina de quadrupedibus,* very likely date from the 8th century.

Early translations into English. But the earliest literary prose dates from the late 9th century, when King Alfred, eager to improve the state of English learning, led a vigorous program to translate into English "certain books that are necessary for all men to know." Alfred himself translated St. Gregory I the Great's *Pastoral Care,* Boethius' *Consolation of Philosophy,* St. Augustine of Hippo's *Soliloquies* and the first 50 psalms. His *Pastoral Care* is a fairly literal translation, but his Boethius is extensively restructured and revised to make explicit the Christian message that medieval commentators saw in that work. He revised the *Soliloquies* even more radically, departing from his source to draw from St. Jerome, Gregory, and other works by Augustine. Alfred's prefaces to these works are of great historical interest.

At Alfred's urging Bishop Werferth of Worcester translated the *Dialogues* of Gregory; probably Alfred also inspired anonymous scholars to translate Bede's *Historia ecclesiastica* and Paulus Orosius' *Historiarum adversum paganos libri vii* ("History Opposing the Pagans, In Seven Books"). Both of these works are much abridged; the Bede translation follows its source slavishly, but the translator of Orosius added many details of northern European geography and also accounts of the voyages of Ohthere the Norwegian and Wulfstan the Dane. These accounts, in addition to their geographical interest, show that friendly commerce between England and Scandinavia was possible even during the Danish wars. The *Anglo-Saxon Chronicle* probably originated in Alfred's reign. Its earliest annals (from 60 BC) are laconic, except the entry for 755, which records in detail a feud between the West Saxon king Cynewulf and the would-be usurper Cyneheard. The entries covering the Danish wars of the late 9th century are much fuller, and those running from the reign of Aethelred I to the Norman Conquest in 1066 (when the *Chronicle* exists in several versions) contain many passages of excellent writing. The early 10th century is not notable for literary production, but some of the homilies in the Vercelli Book and the Blickling manuscript (Scheide Library, Princeton University) may belong to that period.

The *Anglo-Saxon Chronicle*

Late 10th- and 11th-century prose. The Benedictine reform of the mid-10th century brought about a period of lively literary activity. Aethelwold, bishop of Winchester and one of the leaders of the reform, translated the Rule of St. Benedict. But the greatest and most prolific writer of this period was his pupil Aelfric, abbot of Eynsham, whose works include three cycles of 40 homilies each (*Catholic Homilies,* 2 vol., and the *Lives of the Saints*), as well as

homilies not in these cycles; a Latin grammar; a treatise on science; pastoral letters; and several translations. His Latin *Colloquy,* supplied with an Old English version by an anonymous glossarist, gives a charming picture of everyday life in Anglo-Saxon England. Aelfric wrote with lucidity and astonishing beauty, using the rhetorical devices of Latin literature frequently but without ostentation; his later alliterative prose, which loosely imitates the rhythms of Old English poetry, influenced writers long after the Norman Conquest. Wulfstan, archbishop of York, wrote legal codes, both civil and ecclesiastical, and a number of homilies, including *Sermo Lupi ad Anglos* ("Wulf's Address to the English"), a ferocious denunciation of the morals of his time. To judge from the number of extant manuscripts, these two writers were enormously popular. Byrhtferth of Ramsey wrote several Latin works and the *Enchiridion,* a textbook on the calendar, notable for its ornate style. Numerous anonymous works, some of very high quality, were produced in this period, including homilies, saints' lives, dialogues, and translations of such works as the Gospels, several Old Testament books, liturgical texts, monastic rules, penitential handbooks, and the romance *Apollonius of Tyre* (translated from Latin but probably derived from a Greek original). The works of the monastic reform were written during a few remarkable decades around the turn of the millennium. Little original work can be securely dated to the period after Wulfstan's death (1023), but the continued vigour of the *Anglo-Saxon Chronicle* shows that good Old English prose was written right up to the Norman Conquest. By the end of this period English had been established as a literary language with a polish and versatility unequaled among European vernaculars.

The Early Middle English period

POETRY

The Norman Conquest worked no immediate transformation on either the language or literature of the English. Older poetry continued to be copied during the last half of the 11th century; two poems of the early 12th century—"Durham," which praises that city's cathedral and its relics, and "Instructions for Christians," a didactic piece—show that correct alliterative verse could be composed well after 1066. But even before the Conquest rhyme had begun to supplant rather than supplement alliteration in some poems, which continued to use the older four-stress line but the rhythms of which varied from the set types used in classical Old English verse. A post-Conquest example is "The Grave," which contains several rhyming lines; a poem from the *Anglo-Saxon Chronicle* on the death of William the Conqueror, lamenting his cruelty and greed, has more rhyme than alliteration.

Influence of French poetry. By the end of the 12th century English poetry had been so heavily influenced by French models that such a work as the long epic *Brut* (*c.* 1200) by Lawamon, a Worcestershire priest, seems archaic for mixing alliterative lines with rhyming couplets while generally eschewing French vocabulary. The *Brut* mainly draws upon Wace's Anglo-Norman *Roman de Brut* (1155; based in turn upon Geoffrey of Monmouth's *Historia regum Britanniae,* or *History of the Kings of Britain*), but in Lawamon's hands the Arthurian story takes on a Germanic and heroic flavour largely missing in Wace. The *Brut* exists in two manuscripts, one written shortly after 1200 and the other some 50 years later. That the later version has been extensively modernized and somewhat abridged suggests the speed with which English language and literary tastes were changing in this period. *The Proverbs of Alfred* also were written in the late 12th century; these deliver conventional wisdom in a mixture of rhymed couplets and alliterative lines, and it is hardly likely that any of the material they contain actually originated with the king whose wisdom they celebrate. The early 13th-century *Bestiary* mixes alliterative lines, three- and four-stress couplets, and septenary lines, but the logic behind this mix is more obvious than in the *Brut* and the *Proverbs,* for the poet was imitating the varied metres of his Latin source. More regular in form than these poems is the anonymous *Poema morale* in septenary couplets, in which an old man delivers a dose of moral advice to his presumably younger audience.

Lawamon's *Brut*

By far the most brilliant poem of this period is *The Owl and the Nightingale* (written after 1189), an example of the popular debate genre. The two birds argue topics ranging from their hygienic habits, looks, and songs to marriage, prognostication, and the proper modes of worship. The nightingale stands for the joyous aspects of life, the owl for the sombre; there is no clear winner, but the debate ends as the birds go off to state their cases to one Nicholas of Guildford, a wise man. The poem is learned in the clerical tradition but wears its learning lightly as the disputants speak in colloquial and sometimes earthy language. Like the *Poema morale, The Owl and the Nightingale* is metrically regular (octosyllabic couplets), but it uses the French metre with an assurance that is astonishing in so early a poem.

Didactic poetry. The 13th century saw a rise in the popularity of long didactic poems presenting biblical narrative, saints' lives, or moral instruction for those untutored in Latin or French. The most idiosyncratic of these is the *Ormulum* by Orm, an Augustinian canon in the north of England. Written in some 20,000 lines arranged in unrhymed but metrically rigid couplets, the work is interesting mainly in that the manuscript that preserves it is Orm's autograph and shows his somewhat fussy (and ineffectual) efforts to reform and regularize English spelling. Other biblical paraphrases are *Genesis and Exodus, Jacob and Joseph,* and the vast *Cursor mundi,* whose subject, as its title suggests, is the whole history of the world. An especially popular work was the *South English Legendary,* which began as a miscellaneous collection of saints' lives but was expanded by later redactors and rearranged in the order of the church calendar. The didactic tradition continued into the 14th century with Robert Mannyng's *Handlyng Synne,* a confessional manual the expected dryness of which is relieved by the insertion of lively narratives, and the *Pricke of Conscience,* a summary of theology sometimes attributed to Richard Rolle.

Verse romance. The earliest examples of verse romance, a genre that would remain popular through the Middle Ages, appeared in the 13th century. *King Horn* and *Floris and Blauncheflour* both are preserved in a manuscript of around 1250. *King Horn,* oddly written in short two- and three-stress lines, is a vigorous tale of a kingdom lost and regained, with a subplot concerning Horn's love for Princess Rymenhild. *Floris and Blauncheflour* is more exotic, being the tale of a pair of royal lovers who become separated and, after various adventures in eastern lands, reunited. Not much later than these is *The Lay of Havelok the Dane,* a tale of princely love and adventure similar to *King Horn* but more competently executed. Many more such romances were produced in the 14th century. Popular subgenres were "the matter of Britain" (Arthurian romances such as *Of Arthour and of Merlin* and *Ywain and Gawain*); "the matter of Troy" (tales of antiquity such as *The Seege of Troye* and *Kyng Alisaunder*); and the English Breton lays, stories of otherworldly magic, such as *Lai le Freine* and *Sir Orfeo,* modeled after those of professional Breton storytellers. These relatively unsophisticated works were no doubt written for a bourgeois audience, and the manuscripts that preserve them are early examples of commercial book production. The humorous beast epic makes its first appearance in the 13th century in *The Fox and the Wolf,* taken indirectly from the Old French *Roman de Renart.* In the same manuscript with this work is *Dame Sirith,* the earliest English fabliau. Another sort of humour is found in *The Land of Cockayne,* which depicts a utopia better than heaven, where rivers run with oil, milk, honey, and wine, geese fly about already roasted, and monks hunt with hawks and dance with nuns.

Floris and Blauncheflour

The lyric. The lyric was virtually unknown to Old English poets: poems like "Deor" and "Wulf and Eadwacer," which have been called lyrics, are thematically different from those that began to circulate orally in the 12th century and to be written down in great numbers in the 13th; and these Old English poems have a stronger narrative component than the later productions. The most frequent

topics in the Middle English secular lyric are springtime and romantic love; many rework such themes tediously, but some, such as "Foweles in the frith" (13th century) and "Ich am of Irlaunde" (14th century), convey strong emotions in a few lines. Two lyrics of the early 13th century, "Mirie it is while sumer ilast" and "Sumer is icumen in," are preserved with musical settings, and probably most of the others were meant to be sung. The dominant mood of the religious lyrics is passionate: the poets sorrow for Christ on the Cross and for Mary, celebrate the "five joys" of Mary, and import language from love poetry to express religious devotion. Excellent early examples are "Nou goth sonne under wod" and "Stond wel, moder, ounder rode." Many of the lyrics are preserved in manuscript anthologies, of which the best is British Library manuscript Harley 2253 from the early 14th century. The love poems in this collection, such as "Alysoun" and "Blow, Northerne Wynd," take after the poems of the Provençal troubadours but are less formal and abstract and therefore more lively. The religious lyrics also are of high quality; but the most remarkable of the Harley Lyrics, "The Man in the Moon," far from being about love or religion, imagines the man in the Moon as a simple peasant, sympathizes with his hard life, and offers him some useful advice on how to best the village hayward.

A poem such as "The Man in the Moon" serves as a reminder that, although the poetry of the early Middle English period is increasingly influenced by the Anglo-Norman literature produced for the courts, it is seldom "courtly." Most English poets, whether writing about kings or peasants, looked at life from a middle-class perspective. If their work sometimes lacks sophistication, it nevertheless has a vitality that comes from preoccupation with daily affairs; its practicality, as much as its language, gives it a distinctly English flavour.

PROSE

Old English prose texts were copied for more than a century after the Norman Conquest; the homilies of Aelfric were especially popular, and King Alfred's translations of Boethius and Augustine survive only in 12th-century manuscripts. In the early 13th century an anonymous worker at Worcester supplied glosses to certain words in a number of Old English manuscripts, demonstrating that by this time the older language was beginning to pose difficulties for readers.

The composition of English prose also continued without interruption. Two manuscripts of the *Anglo-Saxon Chronicle* exhibit very strong prose for years after the Conquest, and one of these, *The Peterborough Chronicle,* continues to the year 1154. Two manuscripts of around 1200 contain 12th-century sermons, and another has a workman-like compilation on the "Vices and Virtues," composed around 1200. But the English language faced stiff competition from both Anglo-Norman (the insular dialect of French being used increasingly in the monasteries) and Latin, a language intelligible to speakers of both English and French. It was inevitable, then, that the production of English prose should decline in quantity, if not in quality. The great prose works of this period were composed mainly for those who could read only English—women especially. In the West Midlands the Old English alliterative prose tradition remained very much alive into the 13th century, when the several texts known collectively as the Katherine Group were written. "St. Katherine," "St. Margaret," and "St. Juliana," found togeiher in a single manuscript, have rhythms strongly reminiscent of those of Aelfric and Wulfstan. So, to a lesser extent, do "Hali Meithhad" ("Holy Maidenhood") and "Sawles Warde" ("The Guardianship of the Soul") from the same book, but newer influences can be seen in these works as well: as the title of another devotional piece, "The Wohunge of Ure Lauerd" ("The Wooing of Our Lord"), suggests, the prose of this time often has a rapturous, even sensual flavour, and, like the poetry, it frequently employs the language of love to express religious fervour.

Composition in English, Anglo-Norman, and Latin

Further removed from the Old English prose tradition, though often associated with the Katherine Group, is the *Ancrene Wisse* ("Guide for Anchoresses," also known as the *Ancrene Riwle,* or "Rule for Anchoresses"), a manual for the guidance of women recluses outside the regular orders. This anonymous work, which was translated into French and Latin and remained popular until the 16th century, is notable for its humanity, practicality, and insight into human nature but even more for its brilliant style. Like the other prose of its time, it uses alliteration as ornament, but it is more indebted to new fashions in preaching, which had originated in the universities, than to native traditions. With its richly figurative language, rhetorically crafted sentences, and carefully logical divisions and subdivisions, it manages to achieve in English the effects that such contemporary writers as John of Salisbury and Walter Map were striving for in Latin.

Little noteworthy prose was written in the late 13th century. In the early 14th century Dan Michel produced in Kentish the *Ayenbite of Inwit* ("Prick of Conscience"), a translation from French. But the best prose of this time is by the mystic Richard Rolle, the hermit of Hampole, whose English tracts include *The Commandment, Meditations on the Passion,* and *The Form of Perfect Living,* among others. His intense and stylized prose was among the most popular of the 14th century and inspired such later works as Walter Hilton's *Scale of Perfection,* Julian of Norwich's *Sixteen Revelations of Divine Love,* and the anonymous *Cloud of Unknowing.* (P.S.Ba.)

The later Middle English and early Renaissance periods

One of the most important factors in the nature and development of English literature between about 1350 and 1550 was the peculiar linguistic situation in England at the beginning of the period. Among the small minority of the population that could be regarded as literate, bilingualism and even trilingualism were common. Insofar as it was considered a serious literary medium at all, English was obliged to compete on uneven terms with Latin and with the Anglo-Norman dialect of French widely used in England at the time. Moreover, extreme dialectal diversity within English itself made it difficult for vernacular writings, irrespective of their literary pretensions, to circulate very far outside their immediate areas of composition, a disadvantage not suffered by writings in Anglo-Norman and Latin. Literary culture managed to survive and in fact to flourish in the face of such potentially crushing factors as the catastrophic mortality of the Black Death (1347–51), chronic external and internal military conflicts in the form of the Hundred Years' War and the Wars of the Roses, and serious social, political, and religious unrest, as evinced in the Peasants' Revolt (1381) and the rise of Lollardism (centred on the religious teachings of John Wycliffe). All the more remarkable then was the literary and linguistic revolution that took place in England between about 1350 and 1400 and that was slowly and soberly consolidated over the subsequent 150 years.

LATER MIDDLE ENGLISH POETRY

The revival of alliterative poetry. The most puzzling episode in the development of later Middle English literature was the apparently sudden reappearance of unrhymed alliterative poetry in the mid-14th century. Debate continues as to whether the group of long, serious, and sometimes learned poems written between about 1350 and the first decade of the 15th century should be regarded as an "alliterative revival" or rather as the late flowering of a largely lost native tradition stretching back to the Old English period. The earliest examples of the phenomenon, *William of Palerne* and *Winner and Waster,* are both datable to the 1350s, but neither poem exhibits to the full all the characteristics of the slightly later poems central to the movement. *William of Palerne,* condescendingly commissioned by a nobleman for the benefit of "them that know no French," is a homely paraphrase of a courtly continental romance, the only poem in the group to take love as its central theme. The poet's technical competence in handling the difficult syntax and diction of the alliterative style is not, however, to be compared with that of *Winner and Waster*'s author, who exhibits full mastery of the

form, particularly in brilliant descriptions of setting and spectacle. This poem's topical concern with social satire links it primarily with another, less formal body of alliterative verse, of which William Langland's *Piers Plowman* was the principal representative and exemplar. Indeed, *Winner and Waster*, with its sense of social commitment and occasional apocalyptic gesture, may well have served as a source of inspiration for Langland himself.

The expression alliterative revival should not be taken to imply a return to the principles of classical Old English versification. The authors of the later 14th-century alliterative poems either inherited or developed their own conventions, which resemble those of the Old English tradition in only the most general way. The syntax and particularly the diction of later Middle English alliterative verse were also distinctive, and the search for alliterating phrases and constructions led to the extensive use of archaic, technical, and dialectal words. Hunts, feasts, battles, storms, and landscapes were described with a brilliant concretion of detail rarely paralleled since, while the abler poets also contrived subtle modulations of the staple verse-paragraph to accommodate dialogue, discourse, and argument. Among the poems central to the movement were three pieces dealing with the life and legends of Alexander, the massive *Destruction of Troy*, and the *Siege of Jerusalem*. The fact that all of these derived from various Latin sources suggests that the anonymous poets were likely to have been clerics with a strong, if bookish, historical sense of their romance "matters." The "matter of Britain" was represented by an outstanding composition, the alliterative *Morte Arthure*, an epic portrayal of King Arthur's conquests in Europe and his eventual fall, combining a strong narrative thrust with considerable density and subtlety of diction. A gathering sense of inevitable transitoriness gradually tempers the virile realization of heroic idealism, and it is not surprising to find that the poem was later used by Sir Thomas Malory as a source for his prose account, *Le Morte Darthur* (completed *c.* 1470).

The alliterative movement would today be regarded as a curious but inconsiderable episode, were it not for four other poems now generally attributed to a single anonymous author: the chivalric romance *Sir Gawayne and the Grene Knight*, two homiletic poems called *Patience* and *Purity* (or *Cleanness*), and an elegiac dream vision known as *Pearl*, all miraculously preserved in a single manuscript dated *c.* 1400. The poet of *Sir Gawayne* far exceeded the other alliterative writers in his mastery of form and style, and though he wrote ultimately as a moralist, human warmth and sympathy (often taking comic form) were also close to the heart of his work. *Patience* relates the biblical story of Jonah as a human comedy of petulance and irascibility set off against God's benign forbearance. *Purity* imaginatively re-creates several monitory narratives of man's impurity and its consequences in a spectacular display of poetic skill: the Flood, the destruction of Sodom, and Belshazzar's Feast. The poet's principal achievement, however, was *Sir Gawayne*, in which he used the conventional apparatus of chivalric romance to engage in a serious exploration of man's moral conduct in the face of the unknown. The hero, a questing knight of Arthur's court, embodies a combination of the noblest chivalric and spiritual aspirations of the age, but instead of triumphing in the conventional way, he fails when tested (albeit rather unfairly) by mysterious supernatural powers. No paraphrase can hope to recapture the brilliant imaginative resources displayed in the telling of the story and the structuring of the poem as a work of art. The *Pearl* stands somewhat aside from the alliterative movement proper. In common with a number of other poems of the period, it was composed in stanzaic form, with alliteration used for ornamental effect. Technically it is one of the most complex poems in the language, an attempt to work in words an analogy to the jeweler's art. The jeweler-poet is vouchsafed a heavenly vision in which he sees his pearl, the discreet symbol used in the poem for a lost infant daughter who has died to become a bride of Christ. She offers theological consolation for his grief, expounding the way of salvation and the place of human life in a transcendental and extra-temporal view of things.

Sir Gawayne and the Grene Knight

The alliterative movement was primarily confined to poets writing in northern and northwestern England, who showed little regard for courtly, London-based literary developments. It is likely that alliterative poetry, under aristocratic patronage, filled a gap in the literary life of the provinces caused by the decline of Anglo-Norman in the latter half of the 14th century. Alliterative poetry was not unknown in London and the southeast, but it penetrated those areas in a modified form and in poems that dealt with different subject matter.

Piers Plowman

William Langland's long alliterative poem *Piers Plowman* begins with a vision of the world seen from the Malvern Hills in Worcestershire, where, tradition has it, the poet was born and brought up, and where he would have been open to the influence of the alliterative movement. If what he tells about himself in the poem is true (and there is no other source of information), he later lived obscurely in London as an unbeneficed cleric. Langland wrote in the unrhymed alliterative mode, but he modified it in such a way as to make it more accessible to a wider audience by treating the metre more loosely and avoiding the arcane diction of the provincial poets. His poem exists in three versions: A, *Piers Plowman* in its short, early form, dating from the 1360s; B, a major revision and extension of A made in the late 1370s; and C (1380s), a less "literary" version of B, apparently intended to bring its doctrinal issues into clearer focus. The poem takes the form of a series of dream visions dealing with the social and spiritual predicament of later 14th-century England against a sombre apocalyptic backdrop. Realistic and allegorical elements are mingled in a phantasmagoric way, and both the poetic medium and the structure are frequently subverted by the writer's spiritual and didactic impulses. Passages of involuted theological reasoning mingle with scatological satire, and moments of sublime religious feeling appear alongside forthright political comment. This makes it a work of the utmost difficulty, defiant of categorization, but at the same time Langland never fails to convince the reader of the passionate integrity of his writing. His bitter attacks on political and ecclesiastical corruption (especially among the friars) quickly struck chords with his contemporaries. Among minor poems in the same vein were *Mum and the Sothsegger* (*c.* 1399–1406) and a Lollard piece called *Pierce the Ploughman's Creed* (*c.* 1395). In the 16th century *Piers Plowman* was issued as a printed book and was used for apologetic purposes by the early Protestants.

Courtly poetry. Apart from a few late and minor reappearances in Scotland and the northwest of England, the alliterative movement was over before the first quarter of the 15th century had passed. The other major strand in the development of English poetry from about 1350 proved much more durable. The cultivation and refinement of human sentiment with respect to love, already present in earlier 14th-century writings such as the Harley Lyrics, took firm root in English court culture during the reign of Richard II (1377–99). English began to displace Anglo-Norman French as the language spoken at court and in aristocratic circles, and signs of royal and noble patronage for English vernacular writers became evident. These processes undoubtedly created some of the conditions in which a writer of Chaucer's interests and temperament might flourish, but they were encouraged and given direction by his genius in establishing English as a literary language.

Chaucer and Gower. Geoffrey Chaucer, a Londoner of bourgeois origins, was at various times a courtier, diplomat, and civil servant. His poetry frequently (but not always unironically) reflects the views and values associated with the term "courtly." It is in some ways not easy to account for his decision to write in English, and it is not surprising that his earliest substantial poems, the *Book of the Duchess* (*c.* 1370) and the *House of Fame* (*c.* 1380), were heavily indebted to the fashionable French love-vision poetry of the time. Also of French origin was the octosyllabic couplet used in these poems. Chaucer's abandonment of this engaging but ultimately jejune metre in favour of a 10-syllable or iambic pentameter line was a portentous moment for English poetry. His mastery of it

was first revealed in stanzaic form, notably the seven-line stanza (rhyme royal) of the *Parlement of Foules* (*c.* 1382) and *Troilus and Criseyde* (*c.* 1385), and later was extended in the decasyllabic couplets of the prologue to the *Legend of Good Women* and large parts of *The Canterbury Tales*.

Though Chaucer wrote a number of moral and amatory lyrics, which were imitated by his 15th-century followers, his major achievements were in the field of narrative poetry. The early influence of French courtly love poetry (notably the *Roman de la Rose*, which he translated) gave way to an interest in Italian literature. Chaucer was acquainted with Dante's writings and took a story from Petrarch for the substance of his "Clerk's Tale." Two of his major poems, *Troilus and Criseyde* and "The Knight's Tale," were based, respectively, on the *Filostrato* and the *Teseida* of Boccaccio. The *Troilus*, Chaucer's single most ambitious poem, is a moving story of love gained and betrayed set against the background of the Trojan War. As well as being a poem of profound human sympathy and insight, it also has a marked philosophical dimension derived from Chaucer's reading of Boethius' *De consolatione philosophiae*, a work that he also translated in prose. His consummate skill in narrative art, however, was most fully displayed in *The Canterbury Tales* (*c.* 1387–1400), an unfinished series of stories purporting to be told by a group of pilgrims journeying from London to the shrine of St. Thomas Becket and back. The illusion that the individual pilgrims (rather than Chaucer himself) tell their tales gave him an unprecedented freedom of authorial stance, which enabled him to explore the rich fictive potentialities of a number of genres: pious legend (in "The Man of Law's Tale" and "The Prioress's Tale"), fabliaux ("The Shipman's Tale," "The Miller's Tale," and "The Reeve's Tale"), chivalric romance ("The Knight's Tale"), popular romance (parodied in Chaucer's "own" "Tale of Sir Thopas"), beast fable ("The Nun's Priest's Tale" and "The Manciple's Tale") and more—what Dryden later summed up as "God's plenty."

Chaucer's *Canterbury Tales*

A recurrent concern in Chaucer's writings was the refined and sophisticated cultivation of love, commonly described by the modern expression "courtly love." A contemporary French term, *fine amour*, gives a more authentic description of the phenomenon; Chaucer's friend John Gower translated it as "fine loving" in his long poem *Confessio amantis* (begun *c.* 1386). The *Confessio* runs to some 33,000 lines in octosyllabic couplets and takes the form of a collection of exemplary tales placed within the framework of a lover's confession to a priest of Venus. Gower provides an interesting and sometimes refreshing contrast to Chaucer, in that the sober and earnest moral intent behind his writing is always clear, whereas Chaucer can be irritatingly noncommital and evasive. On the other hand, though Gower's verse is generally fluent and pleasing to read, it has a thin homogeneity of texture that cannot compare with the colour and range to be found in the language of his great contemporary. Gower was undoubtedly extremely learned by lay standards, and many classical myths (especially those deriving from Ovid's *Metamorphoses*) make the first of their numerous appearances in English literature in the *Confessio*. He was also deeply concerned with the moral and social condition of contemporary society, and he dealt with it in two weighty compositions in French and Latin, respectively: the *Mirour de l'omme* (*c.* 1374–78; "The Mirror of Man") and *Vox clamantis* (*c.* 1385).

Gower's *Confessio amantis*

Poetry after Chaucer and Gower. *Courtly poetry.* The numerous 15th-century followers of Chaucer continued to treat the conventional range of courtly and moralizing topics, but only rarely with the intelligence and stylistic accomplishment of their distinguished predecessors. The canon of Chaucer's works began to accumulate delightful but apocryphal trifles such as "The Flower and the Leaf" and "The Assembly of Ladies" (both *c.* 1475), the former, like a surprising quantity of 15th-century verse of this type, purportedly written by a woman. The stock figures of the ardent but endlessly frustrated lover and the irresistible but disdainful lady were cultivated as part of the "game of love" depicted in numerous courtly lyrics. Vernacular literacy spread rapidly among both lay men and women, the influence of French courtly love poetry remaining strong. Aristocratic and knightly versifiers such as Charles, duc d'Orléans (captured at Agincourt in 1415), his "jailer" William de la Pole, duke of Suffolk, and Sir Richard Ros (translator of Alain Chartier's influential *La Belle Dame sans merci*) were widely read and imitated among the gentry and in bourgeois circles well into the 16th century.

Both Chaucer and Gower had to some extent enjoyed royal and aristocratic patronage, and the active seeking of patronage became a pervasive feature of the 15th-century literary scene. Thomas Hoccleve, a minor civil servant who probably knew Chaucer and claimed to be his disciple, dedicated his *Regiment of Princes* (*c.* 1412), culled from an earlier work of the same name, to the future Henry V. Most of Hoccleve's compositions seem to have been written with an eye to patronage, and though they occasionally yield interesting and unexpected glimpses of his daily and private lives, they have little to recommend them as poetry. Hoccleve's aspiration to be Chaucer's successor was rapidly overshadowed, in sheer bulk if not necessarily in literary merit, by the formidable oeuvre of John Lydgate, a monk at the abbey of Bury St. Edmunds. Lydgate, too, was greatly stimulated at the prospects opened up by distinguished patronage, producing as a result a number of very long pieces that were greatly admired in their day. A staunch Lancastrian, Lydgate dedicated his *Troy Book* and *Life of Our Lady* to Henry V and his *Fall of Princes* (based ultimately on Boccaccio's *De casibus virorum illustrium*) to Humphrey Plantagenet, duke of Gloucester. He also essayed courtly verse in Chaucer's manner (*The Complaint of the Black Knight* and *The Temple of Glas*), but his imitation of the master's style was rarely successful. Both Lydgate and Hoccleve admired above all Chaucer's "eloquence," by which they meant mainly the Latinate elements in his diction. Their own painfully polysyllabic or "aureate" style unfortunately came to be widely imitated for more than a century. In sum, the major 15th-century English poets were generally undistinguished as successors of Chaucer, and for a significant but independent extension of his achievement one must look to the Scots *makaris* ("makers"), among whom were King James I of Scotland, Robert Henryson, and William Dunbar.

John Lydgate

Lydgate's following at court gave him a central place in 15th-century literary life, but the typical concerns shown by his verse do not distinguish it from a great body of religious, moral, historical, and didactic writing, much of it anonymous. A few identifiable provincial writers turn out to have had their own local patrons, often among the country gentry. East Anglia may be said to have produced a minor school in the works of John Capgrave, Osbern Bokenham, and John Metham, among others also active around the middle of the century. Some of the most moving and accomplished verse of the time is to be found in the anonymous lyrics and carols (songs with a refrain) on conventional subjects such as the transience of life, the coming of death, the sufferings of Christ, and other penitential themes. The author of some distinctive poems in this mode was John Audelay of Shropshire, whose style was heavily influenced by the alliterative movement. Literary devotion to the Virgin Mary was particularly prominent and at its best could produce masterpieces of artful simplicity, such as the justly famous "I sing of a maiden that is makeless."

Provincial writers

Popular and secular verse. The art that conceals art was also characteristic of the best popular and secular verse of the period, outside the courtly mode. Some of the shorter verse romances, usually in a form called tail rhyme, were far from negligible: *Ywain and Gawain* from the *Yvain* of Chrétien de Troyes; *Sir Launfal*, after Marie de France's *Lanval*; and *Sir Degrevant*. Humorous and lewd songs, versified tales, folk songs, ballads, and others form a lively but essentially subliterary body of compositions. Oral transmission was probably common, and the survival of much of what is extant is fortuitous. The Percy Folio manuscript, a 17th-century antiquarian collection of such material, may be a fair sampling of the repertoire of the late medieval itinerant entertainer. In addition to a number of more or less execrable popular romances of the

type satirized long before by Chaucer in "Sir Thopas," the Percy manuscript also contains a number of impressive ballads very much like those collected from oral sources in the 18th and 19th centuries. The extent of medieval origin of the poems collected in Francis J. Child's *English and Scottish Popular Ballads* (1882–98) is debatable. Several of the Robin Hood ballads undoubtedly were known in the 15th century, and the characteristic laconically repetitious and incremental style of the ballads is also to be seen in the enigmatic *Corpus Christi Carol*, preserved in an early 16th-century London grocer's commonplace book. In the same manuscript, but in a rather different vein, is *The Nut-Brown Maid*, an enchanting and expertly managed dialogue-poem on female constancy.

Political verse. A genre that does not fit easily into the categories already mentioned is political verse, of which a good deal was written in the 15th century. Much of it was avowedly and often crudely propagandist, especially during the Wars of the Roses, though a piece like the *Agincourt Carol* shows that it was already possible to strike the characteristically English note of insular patriotism soon after 1415. Of particular interest is the *Libel of English Policy* (c. 1436) on another typically English theme of a related kind: "Cherish merchandise, keep the admiralty,/ That we be masters of the narrow sea."

LATER MIDDLE ENGLISH PROSE

The continuity of a tradition in English prose writing, linking the later with the early Middle English period, is somewhat clearer than that to be detected in verse. The *Ancrene Wisse*, for example, continued to be copied and adapted to suit changing tastes and circumstances. But sudden and brilliant imaginative phenomena like the writings of Chaucer, Langland, and the author of *Sir Gawayne* are not to be found. Instead, there is a steady growth in the composition of religious prose of various kinds and the first appearance of secular prose in any quantity.

Religious prose. Of the first importance was the development of a sober, analytical, but nonetheless impressive kind of contemplative or mystical prose, represented by Walter Hilton's *Scale of Perfection* and the anonymous *Cloud of Unknowing*. The authors of these pieces certainly knew the more rugged and fervent writings of their earlier 14th-century predecessor Richard Rolle, and to some extent they reacted against what they saw as excesses in the style and content of his work. It is of particular interest to note that the mystical tradition was continued into the 15th century, though in very different ways, by two women writers, Julian of Norwich and Margery Kempe of King's Lynn. Julian, often regarded as the first English woman of letters, underwent a series of mystical experiences in 1373 about which she went on to write in her *Revelations of Divine Love*, one of the foremost works of English spirituality by the standards of any age. Rather different religious experiences went into the making of *The Book of Margery Kempe* (c. 1438), the extraordinary autobiographical record of a highly emotional bourgeoise, apparently dictated to a priest. The nature and status of its spiritual content remain controversial, but its often engaging colloquial style and vivid realization of the medieval scene are of abiding interest.

Mystical writings

Another important branch of the contemplative movement in prose involved the translation of continental Latin texts. A major example, and one of the best loved of all medieval English books in its time, was *The Mirror of the Blessed Life of Jesus Christ* (c. 1410), Nicholas Love's translation of the *Meditationes vitae Christi*, attributed to St. Bonaventure. Love's work was particularly valued by the church as an orthodox counterbalance to the heretical tendencies of the Lollards, who espoused the teachings of John Wycliffe and his circle. The Lollard movement generated a good deal of interesting and stylistically distinctive prose writing, though as the Lollards soon came under threat of death by burning, nearly all of it remains anonymous. A number of English works have been attributed to Wycliffe himself, and the first English translation of the Bible to Wycliffe's disciple John Purvey, but there are no firm grounds for these attributions. The Lollard Bible, which exists in a crude early form and in a more impressive later version (supposedly Purvey's work), was widely read in spite of being under doctrinal suspicion. It later influenced William Tyndale's translation of the New Testament, completed in 1525, and, through Tyndale, the Authorized Version (1611).

Secular prose. Secular compositions and translations in prose also came into prominence in the last quarter of the 14th century, though their stylistic accomplishment does not always match that of the religious tradition. Chaucer's "Tale of Melibeus" and his two astronomical translations, the *Treatise on the Astrolabe* and the *Equatorie of the Planetis*, were relatively modest endeavours beside the massive efforts of John of Trevisa, who translated from Latin both Ranulph Higden's universal history, *Polychronicon* (c. 1385–87), and Bartholomaeus Anglicus' encyclopaedia *De proprietatibus rerum* (1398). Judging by the number of surviving manuscripts, however, the most widely read secular prose work of the period is likely to have been *The Travels of Sir John Mandeville*, the supposed adventures of Sir John Mandeville, knight of St. Albans, on his journeys through Asia to the Orient. Though the work now is believed to be purely fictional, the exotic allure of the *Travels* and the occasionally arch style of their author were popular with the English reading public down to the 18th century.

Mandeville's *Travels*

The 15th century saw the consolidation of English prose as a respectable medium for serious writings of various kinds. The anonymous *Brut* chronicle survives in more manuscripts than any other medieval English work and was instrumental in fostering a new sense of national identity. John Capgrave's *Chronicle of England* (c. 1462) and Sir John Fortescue's *On the Governance of England* (c. 1470) were part of the same trend. At its best, the style of such works could be vigorous and straightforward, close to the language of everyday speech, like that found in the chance survivals of private letters of the period. Best known and most numerous among letters are those of the Paston family of Norfolk, but significant collections were also left by the Celys of London and the Stonors of Oxfordshire. More eccentric prose stylists of the period were the religious controversialist Reginald Pecock and John Skelton, whose "aureate" translation of the *Bibliotheca historica* of Diodorus Siculus stands in marked contrast to the demotic exuberance of his verse.

The crowning achievement of later Middle English prose writing was Sir Thomas Malory's cycle of Arthurian legends, which was given the title *Le Morte Darthur* by William Caxton when he printed his edition in 1485. There is still uncertainty as to the identity of Malory, who described himself as a "knight-prisoner." The characteristic mixture of chivalric nostalgia and tragic feeling with which he imbued his book gave fresh inspiration to the tradition of writing on Arthurian themes. The nature of Malory's artistry eludes easy definition, and the degree to which the effects he achieved were a matter of conscious contrivance on his part is debatable. Much of the *Morte Darthur* was translated from prolix French prose romances, and Malory evidently selected and condensed his material with instinctive mastery as he went along. At the same time he cast narrative and dialogue in the cadences of a virile and natural English prose that admirably matched the nobility of both the characters and the theme.

Malory's Arthurian cycle

MIDDLE ENGLISH DRAMA

Because the manuscripts of medieval English plays were usually ephemeral performance scripts rather than reading matter, very few examples have survived from what once must have been a very large dramatic literature. What little survives from before the 15th century includes some bilingual fragments, indicating that the same play might have been given in English or Anglo-Norman, according to the composition of the audience. From the late 14th century onward two main dramatic genres are discernible, the mystery or Corpus Christi cycles and the morality plays. The mystery plays were long cyclic dramas of the Creation, Fall, and Redemption of mankind, based mostly on biblical narratives. They usually included a selection of Old Testament episodes (such as the stories of Cain and Abel and Abraham and Isaac) but concentrated mainly on

Mystery and morality plays

the life and Passion of Jesus Christ. They always ended with the Last Judgment. The cycles were generally financed and performed by the craft guilds and staged on wagons in the streets and squares of the towns. Texts of the cycles staged at York, Chester, Wakefield, and at an unstated location in East Anglia have survived, together with fragments from Coventry, Newcastle, and Norwich. Their literary quality is uneven, but the York cycle (probably the oldest) has a most impressively realized version of Christ's Passion by a dramatist influenced by the alliterative style in verse. Wakefield has several particularly brilliant plays, attributed to the anonymous Wakefield Master, and his *Second Shepherds' Play* is one of the masterpieces of medieval English literature. The morality plays were allegorical dramas depicting the progress of a single character, representing the whole of mankind, from the cradle to the grave and sometimes beyond. The other dramatis personae might include God and the Devil but usually consisted of personified abstractions, such as the Vices and Virtues, Death, Penance, Mercy, and so forth. An interesting and varied collection of the moralities is known as the Macro Plays (*The Castle of Perseverance, Wisdom, Mankind*), but the single most impressive piece is undoubtedly *Everyman,* a superb English rendering of a Dutch play on the subject of the coming of death. Both the mystery and morality plays have been frequently revived and performed in the 20th century.

THE TRANSITION FROM MEDIEVAL TO RENAISSANCE

Transition from medieval to Renaissance

The 15th century was a major period of growth in lay literacy, a process powerfully expedited by the introduction into England of printing by William Caxton in 1476. Caxton's Malory (1485) was published in the same year that Henry Tudor acceded to the throne as Henry VII, and the period from this time to the mid-16th century has been called the transition from medieval to Renaissance in English literature. A typical figure was the translator Alexander Barclay. His *Eclogues* (*c.* 1515), drawn from 15th-century Italian humanist sources, was an early essay in the fashionable Renaissance genre of pastoral, while his rendering of Sebastian Brant's *Narrenschiff* as *The Ship of Fools* (1509) is a thoroughly medieval satire on contemporary folly and corruption. *The Passetyme of Pleasure* (1506) by Stephen Hawes, ostensibly an allegorical romance in Lydgate's manner, unexpectedly adumbrates the great Tudor theme of academic cultivation as a necessary accomplishment of the courtly knight or gentleman.

The themes of education and good government predominate in the new humanist writing of the 16th century, both in discursive prose (such as Sir Thomas Elyot's *Boke Named the Governour* and Roger Ascham's *Toxophilus* and *Scholemaster*) and in the drama (the plays of Henry Medwall and Richard Rastall). The preeminent work of English humanism, Sir Thomas More's *Utopia* (1516), was composed in Latin and appeared in an English translation in 1551. Undoubtedly the most distinctive voice in the poetry of the time was that of John Skelton, tutor to Henry VII's sons and author of an extraordinary range of writing, often in an equally extraordinary style. His works include a long play, *Magnyfycence,* like his *Bowge of Courte* an allegorical satire on court intrigue; intemperate satirical invectives, such as *Collyn Clout* and *Why Come Ye Nat to Courte?* (both 1522); and unusual reflexive essays on the role of the poet and poetry, in *Speke, Parrot* (written 1521) and *The Garland of Laurel* (1523). The first half of the 16th century was also a notable period for courtly lyric verse in the stricter sense of poems with musical settings, such as those found in the Devonshire manuscript. This is very much the literary milieu of the "courtly makers" Sir Thomas Wyatt and Henry Howard, earl of Surrey, but though the courtly context of much of their writing is of medieval origin, their most distinctive achievements look to the future. Poems like Wyatt's "They flee from me" and "Whoso list to hunt" vibrate with personal feeling at odds with the medieval convention of anonymity, while Surrey's translations from the *Aeneid* introduce blank verse (unrhymed iambic pentameter) into English for the first time, providing an essential foundation for the achievements of Shakespeare and Milton. (Ri.B.)

The Renaissance period: 1550–1660

LITERATURE AND THE AGE

In a tradition of literature remarkable for its exacting and brilliant achievements, the Elizabethan and early Stuart periods have been said to represent the most brilliant century of all. (The reign of Elizabeth I began in 1558 and ended with her death in 1603; she was succeeded by the Stuart king James VI of Scotland, who took the title James I of England as well. English literature of his reign as James I, from 1603 to 1625, is properly called Jacobean.) These years produced a gallery of authors of genius, some of whom have never been surpassed, and conferred on scores of lesser talents the enviable ability to write with fluency, imagination, and verve. From one point of view, this sudden renaissance looks radiant, confident, heroic—and belated, but all the more dazzling for its belatedness. Yet from another point of view, this was a time of unusually traumatic strain, in which English society underwent massive disruptions that transformed it on every front and decisively affected the life of every individual. In the brief, intense moment in which England assimilated the European Renaissance, the circumstances that made the assimilation possible were already disintegrating and calling into question the newly won certainties, as well as the older truths that they were dislodging. This doubleness, of new possibilities and new doubts simultaneously apprehended, gives the literature its unrivaled intensity.

Social conditions. In this period England's population doubled; prices rocketed, rents followed, old social loyalties dissolved, and new industrial, agricultural, and commercial veins were first tapped. Real wages hit an all-time low in the 1620s, and social relations were plunged into a state of unprecedented fluidity from which the merchant and ambitious lesser gentleman profited at the expense of the aristocrat and labourer, as satires and comedies current from the 1590s complain. Behind the Elizabethan vogue for pastoral poetry lies the fact of the prosperity of the enclosing sheep farmer, who aggressively sought to increase pasture at the expense of the peasantry. Tudor platitudes about order and degree could neither combat nor survive the challenge posed to rank by these arrivistes. The position of the crown, politically dominant yet financially insecure, had always been potentially unstable, and when Charles I lost the confidence of his greater subjects in the 1640s his authority crumbled. Meanwhile, the huge body of poor fell ever further behind the rich; the pamphlets of Thomas Harman (1566) and Robert Greene (1591–92), and Shakespeare's *King Lear* (1605), provide glimpses of a horrific world of vagabondage and crime, the Elizabethans' biggest, unsolvable social problem.

Intellectual and religious revolution. The barely disguised social ferment was accompanied by an intellectual revolution, as the medieval synthesis collapsed before the new science, new religion, and new humanism. While modern mechanical technologies were pressed into service by the Stuarts to create the scenic wonders of the court masque, the discoveries of astronomers and explorers were redrawing the cosmos in a way that was profoundly disturbing:

> And freely men confess that this world's spent,
> When in the planets, and the firmament
> They seek so many new . . .
>
> (John Donne, *The First Anniversary,* 1611)

The majority of people were more immediately affected by the religious revolutions of the 16th century. The man in early adulthood at the accession of Elizabeth in 1558 would, by her death in 1603, have been vouchsafed an unusually disillusioning insight into the duty owed by private conscience to the needs of the state. The Tudor church was an instrument of social and political coercion, yet the mid-century controversies over the faith had already wrecked any easy confidence in the authority of doctrines and forms and had taught men to question carefully the rationale of their own beliefs (as Donne does in his third *Satire, c.* 1596). The Elizabethan ecclesiastical compromise was the object of continual criticism, both from radicals within (who desired progressive reforms, such as the abolition of bishops) and from papists without (who

desired the return of England to the Roman Catholic fold), but the incipient liberalism of individuals like John Milton and William Chillingworth was held in check by the majority's unwillingness to tolerate a plurality of religions in a supposedly unitary state. Nor was the Calvinist orthodoxy that cradled most English writers comforting, for it told them that they were corrupt, unfree, unable to earn their own salvations, and subject to heavenly judgments that were arbitrary and absolute. It deeply informs the world of the Jacobean tragedies, whose heroes are not masters of their fates but victims of divine purposes that are terrifying yet inscrutable.

The race for cultural development. The third complicating factor was the race to catch up with continental developments in arts and philosophy. The Tudors badly needed to create a class of educated diplomats, statesmen, and officials and to dignify their court by making it a fount of cultural as well as political patronage. The new learning, widely disseminated through the Erasmian educational programs of such men as John Colet and Sir Thomas Elyot, proposed to use a systematic schooling in Latin authors and some Greek to encourage in the social elites a flexibility of mind and civilized serviceableness by which enlightened princely government could walk hand in hand with responsible scholarship. Humanism fostered an intimate familiarity with the classics that was a powerful incentive for the creation of an English literature of answerable dignity. It fostered as well a practical, secular piety that left its impress everywhere on Elizabethan writing. Humanism's effect, however, was modified by the simultaneous impact of the flourishing continental cultures, particularly the Italian. Repeatedly, crucial innovations in English letters developed resources originating from Italy, such as the sonnet of Petrarch, the epic of Ariosto, the pastoral of Sannazzaro, the canzone, and blank verse, and values imported with these forms were in competition with the humanists' ethical preoccupations. Social ideals of wit, many-sidedness, and *sprezzatura* (accomplishment mixed with unaffectedness) were imbibed from Baldassare Castiglione's *Il cortegiano,* translated as *The Courtyer* by Sir Thomas Hoby in 1561, and Elizabethan court poetry is steeped in Castiglione's aristocratic Neoplatonism, his notions of universal proportion, and the love of beauty as the path to virtue. Equally significant was the welcome afforded to Niccolò Machiavelli, whose lessons were vilified publicly and absorbed in private. *The Prince,* written in 1513, was unavailable in English until 1640, but as early as the 1580s Gabriel Harvey, a friend of the poet Edmund Spenser, can be found enthusiastically hailing its author as the apostle of modern pragmatism. "We are much beholden to Machiavel and others," said Bacon, "that write what men do, and not what they ought to do."

The mark of humanism

So the literary revival occurred in a society deeply torn and rife with tensions, uncertainties, and competing versions of order and authority, religion and status, sex and the self. The Elizabethan compromise was exactly that; the Tudor pretense that all the nation thought the same disguised the actual fragmentation of the old consensus under the strain of change. The new scientific knowledge proved both man's littleness and his power to command nature; against the Calvinist idea of man's helplessness pulled the humanist faith in his dignity, especially that conviction, derived from the reading of Seneca and so characteristic of the period, of man's constancy and fortitude, his heroic and almost divine capacity for self-determination. It was still possible for Elizabeth to hold these divergent tendencies together in a single, heterogeneous culture, but under her successors they would eventually fly apart. The philosophers speaking for the new century would be Francis Bacon, who argued for the gradual advancement of science through patient accumulation of experiments, and the skeptic Michel de Montaigne (his *Essais* translated from the French by John Florio, 1603), who denied that it was possible to formulate any general principles of knowledge.

Cutting across all of these was the persistence of popular habits of thought and expression. Both humanism and puritanism set themselves against vulgar ignorance and folk tradition, but, fortunately, neither could remain aloof for long from the robustness of popular taste. Sir Philip Sidney, in England's first neoclassical literary treatise, *The Defence of Poesie* (written *c.* 1578–1583, published 1595), candidly admitted that "the old song of Percy and Douglas" would move his heart "more than with a trumpet," and his *Arcadia* is a representative instance of the continual, fruitful cross-fertilization of genres in this period—the contamination of aristocratic pastoral with popular tale, the lyric with the ballad, comedy with romance, tragedy with satire, and poetry with prose. The language, too, was undergoing a rapid expansion that all classes contributed to and benefited from, sophisticated literature borrowing without shame the idioms of colloquial speech. Macbeth's allusion to heaven peeping "through the blanket of the dark" only became a problem in an age when tragic dignity implied politeness, when it was below the dignity of a tragic hero to mention so lowly an object as a blanket. The Elizabethans' ability to address themselves to several audiences simultaneously and to bring into relation opposed experiences, emphases, and worldviews invested their writing with complexity and power.

Influence of popular taste

ELIZABETHAN POETRY AND PROSE

English poetry and prose burst into sudden glory in the late 1570s. A decisive shift of taste toward a fluent artistry self-consciously displaying its own grace and sophistication was announced in the works of Spenser and Sidney. It was accompanied by an upsurge in literary production that came to fruition in the 1590s and 1600s, two decades of astonishing productivity by writers of every persuasion and calibre.

The groundwork was laid in the 30 years from 1550, a period of slowly increasing confidence in the literary competence of the language and tremendous advances in education, which for the first time produced a substantial English readership, keen for literature and possessing cultivated tastes. This development was underpinned by the technological maturity and accelerating output (mainly in pious or technical subjects) of Elizabethan printing. The Stationers' Company, which controlled the publication of books, was incorporated in 1557, and Richard Tottel's *Miscellany* (1557) revolutionized the relationship of poet and audience by making publicly available lyric poetry, which hitherto had circulated only among a courtly coterie. Edmund Spenser was the first considerable English poet deliberately to use print for the advertisement of his talents.

Tottel's *Miscellany*

Development of the English language. The prevailing opinion of the language's inadequacy, its lack of "terms" and innate inferiority to the eloquent classical tongues, was combated in the work of the humanists Thomas Wilson, Roger Ascham, and Sir John Cheke, whose treatises on rhetoric, education, and even archery argued in favour of an unaffected vernacular prose and a judicious attitude toward linguistic borrowings. Their stylistic ideals are attractively embodied in Ascham's educational tract *The Scholemaster* (1570), and their tonic effect on that particularly Elizabethan art, translation, can be felt in the earliest important examples, Sir Thomas Hoby's Castiglione (1561) and Sir Thomas North's Plutarch (1579). A further stimulus was the religious upheaval that took place in the middle of the century. The desire of Reformers to address as comprehensive an audience as possible—the bishop and the boy who follows the plough, as Tyndale put it—produced the first true classics of English prose: the reformed Anglican Book of Common Prayer (1549, 1552, 1559); John Foxe's *Actes and Monuments* (1563), which celebrates the martyrs, great and small, of English Protestantism; and the various English versions of Scripture, from William Tyndale's (1525), Miles Coverdale's (1535), and the Geneva Bible (1560) to the syncretic Authorized Version (1611). The latter's combination of grandeur and plainness is justly celebrated, even if it represents an idiom never spoken in heaven or on earth. Nationalism inspired by the Reformation motivated the historical chronicles of the capable and stylish Edward Hall (1548), who bequeathed to Shakespeare the tendentious Tudor interpretation of the 15th century, and of the rather less capable Raphael Holinshed (1577). John

Ponet's remarkable *Short Treatise of Politic Power* (1556) is a vigorous polemic against Mary Tudor, whom he saw as a papist tyrant.

In verse, Tottel's much reprinted *Miscellany* generated a series of imitations and, by popularizing the lyrics of Wyatt and Surrey, carried into the 1570s the tastes of the early Tudor court. The newer poets collected by Tottel and other anthologists include Nicholas Grimald, Richard Edwardes, George Turberville, Barnabe Googe, George Gascoigne, Sir John Harington, and many others, of whom Gascoigne is the most considerable. The modern preference for the ornamental manner of the next generation has eclipsed these poets, who continued the tradition of plain, weighty verse, addressing themselves to ethical and didactic themes and favouring the meditative lyric, satire, and epigram. But their taste for economy, restraint, and aphoristic density was, in the verse of Ben Jonson and Donne, to outlive the cult of elegance. The period's major project was *A Mirror for Magistrates* (1559; enlarged editions 1563, 1578, 1587), a collection of verse laments, by several hands, purporting to be spoken by participants in the Wars of the Roses and preaching the Tudor doctrine of obedience. The quality is uneven, but Thomas Sackville's "Induction" and Thomas Churchyard's *Legend of Shore's Wife* are distinguished, and the intermingling of history, tragedy, and political morality was to be influential on the drama.

Sidney and Spenser. With the work of Sidney and Spenser, Tottel's contributors suddenly began to look old-fashioned. Sir Philip Sidney epitomized the new Renaissance "universal man": a courtier, diplomat, soldier, and poet whose *Defence of Poesie* included the first considered account of the state of English letters. Sidney's treatise defends literature on the ground of its unique power to teach, but his real emphasis is on its delight, its ability to depict the world not as it is but as it ought to be. This quality of "forcefulness or *energia*" he himself demonstrated in his sonnet sequence of unrequited desire, *Astrophel and Stella* (written *c.* 1582, published 1591). His *Arcadia,* in its first version (written *c.* 1577–80), is a pastoral romance in which courtiers disguised as Amazons and shepherds make love and sing delicate experimental verses. The revised version (written *c.* 1580–84, published 1590), vastly expanded but abandoned in mid-sentence, added sprawling plots of heroism in love and war, philosophical and political discourses, and set pieces of aristocratic etiquette. Sidney was a dazzling and assured innovator whose pioneering of new forms and stylistic melody was seminal for his generation. His public fame was as an aristocratic champion of an aggressively Protestant foreign policy, but Elizabeth had no time for idealistic warmongering, and thus his fictions abound with situations of inhibition and withheld satisfactions—unresolved conflicts of desire against restraint, heroism against patience, rebellion against submission—that mirror his own position as an unsuccessful courtier.

Sidney's *Defence of Poesie*

Protestantism also loomed large in the life of Edmund Spenser. He enjoyed the patronage of the Earl of Leicester, who sought to advance militant Protestantism at court, and his poetic manifesto, *The Shepheardes Calender* (1579), covertly praised Archbishop Edmund Grindal, who had been suspended by Elizabeth for his Puritan sympathies. Spenser's masterpiece, *The Faerie Queene* (1590–1609), is an epic of Protestant nationalism in which the villains are infidels or papists, the hero is King Arthur, and the central value is married chastity.

Spenser's *Faerie Queene*

Spenser was one of the humanistically trained breed of public servants, and the *Calender,* an expertly crafted collection of pastoral eclogues, both advertised his talents and announced his epic ambitions, the exquisite lyric gift that it reveals being voiced again in the marriage poems *Epithalamion* (1595) and *Prothalamion* (1596). With *The Faerie Queene* he achieved the central poem of the Elizabethan period. Its form fuses the medieval allegory with the Italian romantic epic; its purpose was "to fashion a gentleman or noble person in virtuous and gentle discipline." The plan was for 12 books (six were completed), focusing on 12 virtues exemplified in the quests of 12 knights from the court of Gloriana, the Faerie Queene, a symbol for Elizabeth herself. Arthur, in quest of Gloriana's love, would appear in each book and come to exemplify Magnificence, the complete man. Spenser took the decorative chivalry of the Elizabethan court festivals and reworked it through a constantly shifting veil of allegory, so that the knight's adventures and loves build into a complex, multileveled portrayal of the moral life. The verse, a spacious and slow-moving nine-lined stanza, and archaic language frequently rise to an unrivaled sensuousness.

The Faerie Queene was a public poem, addressed to the Queen, and politically it echoed the hopes of the Leicester circle for government motivated by godliness and militancy. Spenser's increasing disillusion with the court and with the active life, a disillusion noticeable in the later books and in his bitter satire *Colin Clouts Come Home Againe* of 1591, voiced the fading of these expectations in the last decade of Elizabeth's reign, the beginning of that remarkable failure of political and cultural confidence in the monarchy. In the "Mutabilitie Cantos," melancholy fragments of a projected seventh book, Spenser turned away from the public world altogether, toward the ambiguous consolations of eternity.

The lessons taught by Sidney and Spenser in the cultivation of melodic smoothness and graceful refinement appear to good effect in the subsequent virtuoso outpouring of lyrics and sonnets. These are among the most engaging achievements of the age, though the outpouring was itself partly a product of frustration, as a generation trained to expect office or preferment but faced with courtly parsimony channeled its energies in new directions in search of patronage. For Sidney's fellow courtiers, pastoral and love lyric were also a means of obliquely expressing one's relationship with the Queen, of advancing a proposal or an appeal.

Elizabethan lyric. Virtually every Elizabethan poet tried his hand at the lyric; few, if any, failed to write one that is not still anthologized today. The fashion for interspersing prose fiction with lyric interludes, begun in the *Arcadia,* was continued by Robert Greene and Thomas Lodge (notably in the latter's *Rosalynde,* 1590, the source for Shakespeare's *As You Like It*), and in the theatres plays of every kind were diversified by songs both popular and courtly. Fine examples are in the plays of John Lyly, George Peele, Thomas Nashe, Ben Jonson, and Thomas Dekker (though all, of course, are outshone by Shakespeare's). The most important influence, though, was the outstanding richness of late Tudor music, in both the native tradition of expressive lute song, represented by John Dowland, and the complex Italianate madrigal newly imported by William Byrd and Thomas Morley. The foremost talent among lyricists, Thomas Campion, was composer as well as poet; his songs (four *Bookes of Ayres,* 1601–17) are unsurpassed for their clarity, harmoniousness, and rhythmic subtlety. Even the work of a lesser talent, however, such as Nicholas Breton, is remarkable for the suggestion of depth and poise in the slightest performances; the smoothness and apparent spontaneity of Elizabethan lyric conceals a consciously ordered and laboured artifice, attentive to decorum and rhetorical fitness. These are not personal but public pieces, intended for singing and governed by a Neoplatonic aesthetic in which delight is a means of addressing the moral sense, harmonizing the auditor's mind and attuning it to the discipline of reason and virtue. This necessitates a deliberate narrowing of scope—to the readily comprehensible situations of pastoral or Petrarchan hope and despair—and makes for a certain uniformity of effect, albeit an agreeable one. The lesser talents are well displayed in the miscellanies *The Phoenix Nest* (1593), *Englands Helicon* (1600), and *A Poetical Rhapsody* (1602).

Campion's songs

The sonnet sequence. The publication of Sidney's *Astrophel and Stella* in 1591 generated an equally extraordinary vogue for the sonnet sequence, Sidney's principal imitators being Samuel Daniel, Michael Drayton, Fulke Greville, Spenser, and Shakespeare, and his lesser, Henry Constable, Barnabe Barnes, Giles Fletcher, Thomas Lodge, Richard Barnfield, and many more. *Astrophel* had re-created the Petrarchan world of proud beauty and despairing lover in a single, brilliant stroke, though in English hands the preferred division of the sonnet into three quatrains and a

couplet gave Petrarch's contemplative form a more forensic turn, investing it with an argumentative terseness and epigrammatic sting. Within the common ground shared by the sequences there is much diversity. Only Sidney's endeavours to tell a story, the others being more loosely organized as variations focusing on a central (usually fictional) relationship. Daniel's *Delia* (1592) is eloquent and elegant, dignified and high-minded; Drayton's *Ideas Mirrour* (1594; much revised by 1619) rises to a strongly imagined, passionate intensity; Spenser's *Amoretti* (1595) celebrates, eccentrically, fulfilled sexual love achieved within marriage. Shakespeare's sonnets (published 1609) present a different world altogether, the conventions upside down, the lady no beauty but dark and treacherous, the loved one genuinely beyond considerations of sexual possession because he is a boy. The sonnet tended to gravitate toward correctness or politeness, and for most readers its chief pleasure must have been rhetorical, in its forceful pleading and consciously exhibited artifice, but under the pressure of Shakespeare's urgent metaphysical concerns, dramatic toughness, and shifting and highly charged ironies, the form's conventional limits were exploded.

Other poetic styles. Sonnet and lyric represent one tradition of verse within the period, that most conventionally delineated as Elizabethan, but the picture is complicated by the coexistence of other poetic styles in which ornament was distrusted or turned to different purposes; the sonnet was even parodied by Sir John Davies in his *Gulling Sonnets* (c. 1594) and by the Jesuit poet Robert Southwell. A particular stimulus to experiment was the variety of new possibilities made available by verse translation, from Richard Stanyhurst's extraordinary *Aeneid* (1582), in quantitative hexameter and littered with obscure or invented diction, and Sir John Harington's version of Ariosto's *Orlando furioso* (1591), with its Byronic ease and narrative fluency, to Christopher Marlowe's blank verse rendering of *Lucan's First Book* (published 1600), probably the finest Elizabethan translation.

Epyllion

The genre to benefit most from translation was the epyllion, or little epic. This short narrative in verse was usually on a mythological subject, taking most of its material from Ovid, either his *Metamorphoses* (English version by Arthur Golding, 1565–67) or his *Heroides* (English version by Turberville, 1567). This form flourished from Thomas Lodge's *Scillaes Metamorphosis* (1589) to Francis Beaumont's *Salmacis and Hermaphroditus* (1602) and is best represented by Marlowe's *Hero and Leander* (published 1598) and Shakespeare's *Venus and Adonis* (1593). Ovid's reputation as an esoteric philosopher left its mark on George Chapman's *Ovid's Banquet of Sense* (1595) and Drayton's *Endimion and Phoebe* (1595), in which the love of mortal for goddess becomes a parable of wisdom. But his real attraction was as an authority on the erotic, and most epyllia treat physical love with sophistication and sympathy, unrelieved by the gloss of allegory—a tendency culminating in John Marston's *The Metamorphosis of Pigmalion's Image* (1598), a poem that has shocked tender sensibilities. Inevitably, the shift of attitude had an effect on style: for Marlowe the experience of translating (inaccurately) Ovid's *Amores* meant a gain for *Hero and Leander* in terms of urbanity and, more important, wit.

With the epyllion comes a hint of the tastes of the following reign, and a similar shift of taste can be felt among those poets of the 1590s who began to modify the ornamental style in the direction of native plainness or classical restraint. An astute courtier like Sir John Davies might, in his *Orchestra* (1596) and *Hymns of Astraea* (1599), write confident panegyrics to the aging Elizabeth, but in Sir Walter Raleigh's "Eleventh Book of the Ocean to Cynthia," a kind of broken pastoral eclogue, praise of the Queen is undermined by an obscure but eloquent sense of hopelessness and disillusionment. For Raleigh the complimental manner seems to be disintegrating under the weight of disgrace and isolation at court; his scattered lyrics, notably that contemptuous dismissal of the court, "The Lie," often draw their resonance from the resources of the plain style. Another courtier whose writing suggests similar pressures is Fulke Greville, Lord Brooke. Greville's *Caelica* (published 1633) begins as a conventional sonnet sequence but gradually abandons Neoplatonism for pessimistic reflections on religion and politics. Other works in his sinewy and demanding verse include philosophical treatises and unperformed melodramas (*Alaham* and *Mustapha*) that have a sombre Calvinist tone, presenting man as a vulnerable creature inhabiting a world of unresolved contradictions:

> Oh wearisome condition of humanity!
> Born under one law, to another bound;
> Vainly begot, and yet forbidden vanity,
> Created sick, commanded to be sound.
>
> (*Mustapha*, chorus)

Greville was a friend of the Earl of Essex, whose revolt against Elizabeth ended in 1601 on the scaffold, and other poets on the edge of the Essex circle fueled the taste for aristocratic heroism and individualist ethics. George Chapman's masterpiece, his translation of Homer (1598), is dedicated to Essex, and his original poems are intellectual and recondite, often deliberately cultivating obscurities; his abstruseness is a means of restricting his audience to a worthy, understanding elite. Samuel Daniel, in his verse *Epistles* (1603) written to various noblemen, strikes a mean between plainness and compliment; his *Musophilus* (1599), dedicated to Greville, defends the worth of poetry but says there are too many frivolous wits writing. The cast of Daniel's mind is stoical, and his language is classically precise. His major project was a verse history of *The Civil Wars between the Two Houses of Lancaster and York* (1595–1609), and versified history is also strongly represented in the *Legends* (1593–1607), *Barons' Wars* (1596, 1603), and *Englands Heroicall Epistles* (1597) of Michael Drayton.

Satire

The form really to set its face against Elizabethan politeness was the satire. Satire was related to the complaint, of which there were notable examples by Daniel (*The Complaint of Rosamond,* 1592) and Shakespeare (*The Rape of Lucrece,* 1594), and these are dignified and tragic laments in supple verse, but the Elizabethans mistakenly held the term satire to derive from the Greek *satyros,* a satyr, and so set out to match their manner to their matter and make their verses snarl. In the works of the principal satirists, John Donne (five satires, 1593–98), Joseph Hall (*Virgidemiarum,* 1597–98), and John Marston (*Certaine Satyres* and *The Scourge of Villainy,* 1598), the denunciation of vice and folly repeatedly tips into invective, raillery, and sheer abuse. The versification of Donne's satires is frequently so rough as barely to be verse at all; Hall apologized for not being harsh enough, and Marston was himself pilloried in Ben Jonson's play *Poetaster* (1601) for using ridiculously difficult language. "Vex all the world," wrote Marston to himself, "so that thyself be pleased." The satirists popularized a new persona, that of the malcontent who denounces his society not from above but from within, and their continuing attraction resides in their self-contradictory delight in the world they profess to abhor and their evident fascination with the minutiae of life in court and city. They were enthusiastically followed by Everard Guilpin, Samuel Rowlands, Thomas Middleton, and Cyril Tourneur, and so scandalous was the flood of satires that in 1599 their printing was banned. Thereafter the form survived in Jonson's classically balanced epigrams and poems of the good life, but its more immediate impact was on the drama, in helping to create the vigorously skeptical voices that people *The Revenger's Tragedy* and *Hamlet.*

Prose styles. Description of the development of Elizabethan prose begins with the 1570s. Prose was easily the principal medium in the Elizabethan period, and, despite the mid-century uncertainties over the language's weaknesses and strengths—whether coined and imported words should be admitted; whether the structural modeling of English prose on Latin writing was beneficial or, as Bacon would complain, a pursuit of "choiceness of phrase" at the expense of "soundness of argument"—the general attainment of prose writing was uniformly high, as is often manifested in contexts not conventionally imaginative or "literary," such as tracts, pamphlets, and treatises. The obvious instance of such casual success is Richard Hakluyt's *Principall Navigations, Voiages, and*

Discoveries of the English Nation (1589; expanded 1598–1600), a massive collection of travelers' tales, of which some are highly accomplished narratives. William Harrison's gossipy, entertaining *Description of England* (1577), Philip Stubbes's excitable and humane social critique *The Anatomy of Abuses* (1583), Reginald Scot's anecdotal *Discovery of Witchcraft* (1584), and John Stow's invaluable *Survey of London* (1598) also deserve passing mention. William Kempe's account of his morris dance from London to Norwich, *Kempe's Nine Days' Wonder* (1600), has great charm.

Early prose fiction

The writers listed above all use an unpretentious style, enlivened with a vivid vocabulary; the early prose fiction, on the other hand, delights in ingenious formal embellishment at the expense of narrative economy. This runs up against preferences ingrained in the modern reader by the novel, but Elizabethan fiction is not at all novelistic and finds room for debate, song, and the conscious elaboration of style. The unique exception is George Gascoigne's "Adventures of Master F. J." (1573), a tale of thwarted love set in an English great house, which is the first success in English imaginative prose. Gascoigne's story has a surprising authenticity and almost psychological realism (it may be autobiographical), but even so it is heavily imbued with the influence of Castiglione.

The existence of an audience for polite fiction was signaled in the collections of stories imported from France and Italy by William Painter (1566), Geoffrey Fenton (1577), and George Pettie (1576). Pettie, who claimed not to care "to displease twenty men to please one woman," believed his readership was substantially female. There were later collections by Barnaby Rich (1581) and George Whetstone (1583); historically, their importance was as sources of plots for many Elizabethan plays. The direction fiction was to take was established by John Lyly's *Euphues: The Anatomy of Wit* (1578), which, with its sequel *Euphues and His England* (1580), set a fashion for an extreme rhetorical mannerism that came to be known as "euphuism." The priggish plot of *Euphues*—a rake's fall from virtue and his recovery—is but an excuse for a series of debates, letters, and speechifyings, thick with assonance, antithesis, parallelism, and balance and displaying a pseudoscientific learning. Lyly's style was to be successful on the stage, but in fiction its density and monotony are wearying. The other major prose work of the 1570s, Sidney's *Arcadia,* is no less rhetorical (Abraham Fraunce illustrated his handbook of style *The Arcadian Rhetoric,* 1588, almost entirely with examples from the *Arcadia*), but with Sidney rhetoric is in the service of psychological insight and an exciting plot. Dozens of imitations of *Arcadia* and *Euphues* followed from the pens of Robert Greene, Thomas Lodge, Anthony Munday, Emanuel Forde, and others; none has much distinction.

Prose was to be decisively transformed through its involvement in the bitter and learned controversies of the 1570s and '80s over the reform of the English Church and the problems the controversies raised in matters of authority, obedience, and conscience. The fragile ecclesiastical compromise threatened to collapse under the demands made by Elizabeth's more godly subjects for further reformation, and its defense culminated in Richard Hooker's *Of the Laws of Ecclesiastical Polity* (eight books, 1593–1662), the first English classic of serious prose. Hooker's is a monumental work, structured in massive and complex paragraphs brilliantly recreating the orotund style of Cicero. His air of maturity and detachment has recommended him to modern tastes, but no more than his opponents was he above the cut and thrust of controversy. On the contrary, his magisterial rhetoric was designed all the more effectively to fix blame onto his enemies, and even his account (in books VI–VIII) of the relationship of church and state was deemed too sensitive for publication in the 1590s.

Writings on religious issues

More decisive for English fiction was the appearance of the "Martin Marprelate" tracts of 1588–90. These seven pamphlets argued the Puritan case but with an unpuritanical scurrility and created great scandal by hurling invective and abuse at Elizabeth's bishops with comical gusto. The bishops employed Lyly and Thomas Nashe to reply to Marprelate, and the consequence may be read in Nashe's prose satires of the following decade, especially *Piers Penniless His Supplication to the Devil* (1592), *The Unfortunate Traveller* (1594), and *Lenten Stuffe* (1599), the latter a mock encomium on red herring. Nashe's "extemporal vein" makes fullest use of the flexibility of colloquial speech and delights in nonsense, redundancy, and disconcerting shifts of tone, which demand an answering agility from the reader. His language is probably the most profusely inventive of all Elizabethan writers', and he even makes the low-life pamphlets of Robert Greene (1591–92), with their sensational tales from the underworld, look conventional. His only rival is Thomas Deloney, whose *Jack of Newbury* (1597), *The Gentle Craft* (1597–98), and *Thomas of Reading* (1600) are enduringly attractive for their depiction of the lives of ordinary citizens, interspersed with elements of romance, jest book, and folktale. Deloney's entirely convincing dialogue indicates how important for the development of a flexible prose must have been the example of a flourishing theatre in Elizabethan London. In this respect, as in so many others, the role of the drama was crucial.

ELIZABETHAN AND EARLY STUART DRAMA

Theatre and society. In the Elizabethan and early Stuart period the theatre was the focal point of the age. Public life was shot through with theatricality—monarchs ruled with ostentatious pageantry, rank and status were defined in a rigid code of dress—while on the stages the tensions and contradictions working to change the nation were embodied and played out. More than any other form, the drama addressed itself to the total experience of its society. Playgoing was inexpensive, and the playhouse yards were thronged with apprentices, fishwives, labourers, and the like, but the same play that was performed to citizen spectators in the afternoon would often be restaged at court by night. The drama's power to activate complex, multiple perspectives on a single issue or event resides in its sensitivity to the competing prejudices and sympathies of this diversely minded audience.

Moreover, the theatre was fully responsive to the developing technical sophistication of nondramatic literature. In the hands of Shakespeare the blank verse employed for translation by the Earl of Surrey became a medium infinitely mobile between extremes of formality and intimacy, while prose encompassed both the control of Hooker and the immediacy of Nashe. This was above all a spoken drama, glorying in the theatrical energies of language. And the stage was able to attract the most technically accomplished writers of its day because it offered, uniquely, a literary career with some realistic prospect of financial return. The decisive event was the opening of the first purpose-built London playhouse in 1576, and during the next 70 years some 20 theatres more are known to have operated. The quantity and diversity of plays they commissioned is little short of astonishing.

Humanism and popular taste in the theatre

Theatres in London and the provinces. So the London theatres were a meeting ground of humanism and popular taste. They inherited, on the one hand, a tradition of humanistic drama current at court, the universities, and the Inns of Court (collegiate institutions responsible for legal education). This tradition involved the revival of classical plays and attempts to adapt Latin conventions to English, particularly to reproduce the type of tragedy, with its choruses, ghosts, and sententiously formal verse, associated with Seneca (10 tragedies by Seneca in English translation appeared in 1581). A fine example of the type is *Gorboduc* (1561), by Thomas Sackville and Thomas Norton, a tragedy based on British chronicle history that draws for Elizabeth's benefit a grave political moral about irresponsible government. It is also the first English play in blank verse. On the other hand, all the professional companies performing in London continued also to tour in the provinces, and the stage was never allowed to lose contact with its roots in country show, pastime, and festival. The simple moral scheme that pitted virtues against vices in the mid-Tudor interlude was never entirely submerged in more sophisticated drama, and the "Vice," the tricksy villain of the morality play, survives,

in infinitely more amusing and terrifying form, in Shakespeare's *Richard III*. Another survival was the clown or fool, apt at any moment to step beyond the play's illusion and share jokes directly with the spectators. The intermingling of traditions is clear in two farces, Nicholas Udall's *Ralph Roister Doister* (1553) and the anonymous *Gammer Gurton's Needle* (1559), in which academic pastiche is overlaid with country game; and what the popular tradition did for tragedy is indicated in Thomas Preston's *Cambises, King of Persia* (*c.* 1560), a blood and thunder tyrant play with plenty of energetic spectacle and comedy. A third tradition was that of revelry and masques, practiced at the princely courts across Europe and preserved in England in the witty and impudent productions of the schoolboy troupes of choristers who sometimes played in London alongside the professionals. An early play related to this kind is the first English prose comedy, Gascoigne's *Supposes* (1566), translated from a reveling play in Italian. Courtly revel reached its apogee in England in the ruinously expensive court masques staged for James I and Charles I, magnificent displays of song, dance, and changing scenery performed before a tiny aristocratic audience and glorifying the king. The principal masque writer was Ben Jonson, the scene designer Inigo Jones.

The university wits

Professional playwrights. The first generation of professional playwrights in England was known collectively as the "university wits." Their nickname identifies their social pretensions, but their drama was primarily middle class, patriotic, and romantic. Their preferred subjects were historical or pseudo-historical, mixed with clowning, music, and love interest. At times plot virtually evaporated; George Peele's *Old Wives' Tale* (*c.* 1595) and Nashe's *Summer's Last Will and Testament* (1600) are simply popular shows, charming medleys of comic turns, spectacle, and song. Peele was a civic poet, and his serious plays are bold and pageant-like; *The Arraignment of Paris* (1584) is a pastoral entertainment, designed to compliment Elizabeth. Robert Greene's speciality was comical histories, interweaving a serious plot set among kings with comic action involving clowns. In his *Friar Bacon and Friar Bungay* (1594) and *James IV* (1598) the antics of vulgar characters complement but also criticize the follies of their betters. Only John Lyly, writing for the choristers, endeavoured to achieve a courtly refinement. His *Gallathea* (1584) and *Endimion* (1591) are fantastic comedies in which courtiers, nymphs, and goddesses make rarefied love in intricate, artificial patterns, the very stuff of courtly dreaming.

Christopher Marlowe. Outshining all these is Christopher Marlowe, who alone realized the tragic potential inherent in the popular style, with its bombast and extravagance. His heroes are men of towering ambition who speak blank verse of unprecedented (and occasionally monotonous) elevation, their "high astounding terms" embodying the challenge that they pose to the orthodox norms and limitations of the societies they disrupt. In *Tamburlaine the Great* (two parts, published 1590) and *Edward II* (*c.* 1591; published 1594) traditional political orders are overwhelmed by conquerors and politicians who ignore the boasted legitimacy of weak kings; *The Jew of Malta* (*c.* 1589; published 1633) studies the man of business whose financial acumen and trickery give him unrestrained power; *The Tragical History of Dr. Faustus* (*c.* 1593; published 1604) shows the overthrow of a man whose learning and atheism threaten even God. The main focus of all these plays is on the uselessness of society's moral and religious sanctions against pragmatic, amoral will. They patently address themselves to the anxieties of an age being transformed by new forces in politics, commerce, and science; indeed, the sinister, ironic prologue to *The Jew of Malta* is spoken by Machiavelli. In his own time Marlowe was damned as atheist, homosexual, and libertine, and his plays remain disturbing because his verse makes theatrical presence into the expression of power, enlisting the spectators' sympathies on the side of his gigantic villain-heroes. His plays thus present the spectator with dilemmas that can be neither resolved nor ignored, and they articulate exactly the divided consciousness of their time. There is a similar effect in *The Spanish Tragedy* (*c.* 1591), by Marlowe's friend Thomas Kyd, an early "revenge tragedy" in which the hero seeks justice for the loss of his son but, in an unjust world, can achieve it only by taking the law into his own hands. Kyd's use of Senecan conventions (notably a ghost impatient for revenge) in a Christian setting expresses a genuine conflict of values, making the hero's success at once triumphant and horrifying.

Shakespeare's works. Above all other dramatists stands William Shakespeare, a supreme genius whom it is impossible to characterize briefly. Shakespeare is unequaled as poet and intellect, but he remains elusive. His capacity for assimilation—what Keats called his "negative capability"—means that his work is comprehensively accommodating; every attitude or ideology finds its resemblance there, yet also finds itself subject to criticism and interrogation. In part, Shakespeare achieved this by the total inclusiveness of his aesthetic, by putting clowns in his tragedies and kings in his comedies, juxtaposing public and private, and mingling the artful with the spontaneous; his plays imitate the counterchange of values occurring at large in his society. The sureness and profound popularity of his taste enabled him to lead the English Renaissance without privileging or prejudicing any one of its divergent aspects, while as actor, dramatist, and shareholder in the Lord Chamberlain's players he was involved in the Elizabethan theatre at every level. His career (dated from 1589 to 1613) was exactly coterminous with the period of greatest literary flourishing, and only in his work are the total possibilities of the Renaissance fully realized.

The early histories. Shakespeare's early plays were principally histories and comedies. About a fifth of all Elizabethan plays were histories, but this was the genre that Shakespeare particularly made his own, dramatizing the whole sweep of English history from Richard II to Henry VII in two four-play sequences, an astonishing project carried off with triumphant success. The first sequence, comprising the three *Henry VI* plays and *Richard III* (1589–92), begins as a patriotic celebration of English valour against the French. But this is soon superseded by a mature, disillusioned understanding of the world of politics, culminating in the devastating portrayal of Richard III—probably the first "character," in the modern sense, on the English stage—who boasts in *Henry VI*, Part 3, that he can "set the murtherous Machevil to school." Ostensibly *Richard III* monumentalizes the glorious accession of the dynasty of Tudor, but its realistic depiction of the workings of state power insidiously undercuts such platitudes, and the appeal of Richard's quick-witted individuality is deeply unsettling, short-circuiting any easy moral judgments. The second sequence, *Richard II* (1595), *Henry IV* (two parts, 1596–98), and *Henry V* (1599), begins with the deposing of a bad but legitimate king and follows its consequences through two generations, probing relentlessly at the difficult questions of authority, obedience, and order that it raises. (The Earl of Essex' faction paid for a performance of *Richard II* on the eve of their ill-fated rebellion against Elizabeth.) In the *Henry IV* plays, which are dominated by the massive character of Falstaff and his roguish exploits in Eastcheap, Shakespeare intercuts scenes among the rulers with scenes among those who are ruled to create a multifaceted composite picture of national life at a particular historical moment. The tone of these plays, though, is increasingly pessimistic, and in *Henry V* a patriotic fantasy of English greatness is hedged around with hesitations and qualifications about the validity of the myth of glorious nationhood offered by the Agincourt story. Through all these plays runs a concern for the individual and his subjection to historical and political necessity, a concern that is essentially tragic and anticipates greater plays yet to come. Shakespeare's other history plays, *King John* (*c.* 1591) and *Henry VIII* (1613) approach similar questions through material drawn from John Foxe's *Actes and Monuments*.

History sequences

The early comedies. The early comedies share the popular and romantic forms used by the university wits but overlay them with elements of elegant courtly revel and a sophisticated consciousness of comedy's fragility and artifice. These are festive comedies, giving access to a

Festivity, sportiveness, and the role of nature

society vigorously and imaginatively at play. One group, *The Comedy of Errors* (*c.* 1589–94), *The Taming of the Shrew* (*c.* 1590–94), *The Merry Wives of Windsor* (*c.* 1597–1601), and *Twelfth Night* (1601), are comedies of intrigue, fast moving, often farcical, and placing a high premium on wit. A second group, *The Two Gentlemen of Verona* (*c.* 1592–93), *Love's Labour's Lost* (*c.* 1595), *A Midsummer Night's Dream* (*c.* 1595–96), and *As You Like It* (1599), have as a common denominator a journey to a natural environment, such as a wood or park, in which the restraints governing everyday life are released and the characters are free to remake themselves untrammeled by society's forms, sportiveness providing a space in which the fragmented individual may recover wholeness. All the comedies share a belief in the positive, health-giving powers of play, but none is completely innocent of doubts about the limits that encroach upon the comic space, and in the four plays that approach tragicomedy, *The Merchant of Venice* (*c.* 1596–97), *Much Ado About Nothing* (1598–99), *All's Well That Ends Well* (1602–03), and *Measure for Measure* (1604), festivity is in direct collision with the constraints of normality, with time, business, law, human indifference, treachery, and selfishness. These plays give greater weight to the less optimistic perspectives on society current in the 1590s, and their comic resolutions are openly acknowledged to be only provisional, brought about by manipulation, compromise, or the exclusion of one or more major characters. The unique play *Troilus and Cressida* (*c.* 1601–03) presents a kind of theatrical no man's-land between comedy and tragedy, between satire and savage farce. Shakespeare's reworking of the Trojan War pits heroism against its parody in a way that voices fully the fin-de-siècle sense of man's confused and divided individuality.

The tragedies. The confusions and contradictions of Shakespeare's age find their highest expression in his tragedies. In these extraordinary achievements, all values, hierarchies, and forms are tested and found wanting, and all society's latent conflicts are activated. Shakespeare sets husband against wife, father against child, the individual against society; he uncrowns kings, levels the nobleman with the beggar, and interrogates the gods. Already in the early experimental tragedies *Titus Andronicus* (*c.* 1592–94), with its spectacular violence, and *Romeo and Juliet* (*c.* 1595), with its comedy and romantic tale of adolescent love, Shakespeare had broken away from the conventional Elizabethan understanding of tragedy as a twist of fortune to an infinitely more complex investigation of character and motive, and in *Julius Caesar* (1599) he begins to turn the political interests of the history plays into secular and corporate tragedy, as men fall victim to the unstoppable train of public events set in motion by their private misjudgments. In the major tragedies that follow, Shakespeare's practice cannot be confined to a single general statement that covers all cases, for each tragedy belongs to a separate category: revenge tragedy in *Hamlet* (1600), domestic tragedy in *Othello* (*c.* 1603–04), social tragedy in *King Lear* (1605), political tragedy in *Macbeth* (1606), and heroic tragedy in *Antony and Cleopatra* (1607). In each category Shakespeare's play is exemplary and defines its type; the range and brilliance of this achievement is staggering. The worlds of Shakespeare's heroes are collapsing around them, and their desperate attempts to cope with the collapse uncover the inadequacy of the systems by which they rationalize and justify their existence. The ultimate insight is Lear's irremediable grief over his dead daughter: "Why should a dog, a horse, a rat, have life,/And thou no breath at all?" Before the overwhelming suffering of these great and noble spirits, all consolations are void and all versions of order stand revealed as adventitious. The humanism of the Renaissance is punctured in the very moment of its greatest single product.

Investigation of character and motive

Shakespeare's later works. In his last period, Shakespeare's astonishingly fertile invention returned to experimentation. In *Coriolanus* (1608) he completed his political tragedies, drawing a dispassionate analysis of the dynamics of the secular state; in the scene of the Roman food riot (not unsympathetically depicted) that opens the play is echoed the Warwickshire enclosure riots of 1607. *Timon of Athens* (1607–08) is an unfinished spin-off, a kind of tragical satire. The last group of plays comprises the four romances, *Pericles* (*c.* 1607–08), *Cymbeline* (*c.* 1609–10), *The Winter's Tale* (*c.* 1610–11), and *The Tempest* (1611), which develop a long, philosophical perspective on fortune and suffering. (A final work, *The Two Noble Kinsmen*, 1613, was written in collaboration with John Fletcher.) In these plays Shakespeare's imagination returns to the popular romances of his youth and dwells on mythical themes—wanderings, shipwrecks, the reunion of sundered families, and the resurrection of people long thought dead. There is consolation here, of a sort, beautiful and poetic, but still the romances do not turn aside from the actuality of suffering, chance loss, and unkindness, and Shakespeare's subsidiary theme is a sustained examination of the nature of his own art, which alone makes these consolations possible. Even in this unearthly context a subtle interchange is maintained between the artist's delight in his illusion and his mature awareness of his own disillusionment.

Playwrights after Shakespeare. Shakespeare's perception of a crisis in public norms and private belief became the overriding concern of the drama until the closing of the theatres in 1642. The prevailing manner of the playwrights who succeeded him was realistic, satirical, and antiromantic, and their comedies and tragedies focused predominantly on those two symbolic locations, the city and the court, with their typical activities, the pursuit of wealth and power. "Riches and glory," wrote Sir Walter Raleigh, "Machiavel's two marks to shoot at," had become the universal aims, and this situation was addressed by both "city comedy" and "tragedy of state." Increasingly, it was on the stages that the rethinking of early Stuart assumptions took place.

Theme of the pursuit of wealth and power

On the one hand, in the works of Thomas Heywood, Thomas Dekker, John Day, Samuel Rowley, and others, the old tradition of festive comedy was reoriented toward the celebration of confidence in the dynamically expanding commercial metropolis. Heywood claimed to have been involved in some 200 plays, and they include fantastic adventures starring citizen heroes, spirited, patriotic, and inclined to a leveling attitude in social matters. His masterpiece, *A Woman Kilde with Kindnesse* (1603), is a middle-class tragedy. Dekker was a kindred spirit, best seen in his *Shoemakers' Holiday* (1599), a celebration of citizen brotherliness and Dick Whittington-like success, which nevertheless faces squarely up to the hardships of work, thrift, and the contempt of the great. On the other hand, the very industriousness that the likes of Heywood viewed with civic pride became in the hands of Ben Jonson, George Chapman, John Marston, and Thomas Middleton a sign of aggression, avarice, and anarchy, symptomatic of the sicknesses in society at large.

Ben Jonson. The crucial innovations in satiric comedy were made by Ben Jonson, Shakespeare's friend and nearest rival, who stands at the fountainhead of what has subsequently been the dominant modern comic tradition. His early plays, particularly *Every Man in His Humour* (1598) and *Every Man Out of His Humour* (1599), with their galleries of grotesques, scornful detachment, and rather academic effect, were patently indebted to the verse satires of the 1590s; they introduced to the English stage a vigorous and direct anatomizing of "the time's deformities," the language, habits, and humours of the London scene. Jonson began as a self-appointed social legislator, aristocratic, conservative, and authoritarian, outraged by a society given over to inordinate appetite and egotism and ambitious through his mammoth learning to establish himself as the privileged artist, the fearless and faithful mentor and companion to kings; but he was ill at ease with a court inclined in its masques to prefer flattery to judicious advice. Consequently the greater satires that followed are marked by their gradual accommodations with popular comedy and by their unwillingness to make their implied moral judgments explicit: in *Volpone* (1606) the theatrical brilliance of the villain easily eclipses the sordid legacy hunters whom he deceives; *Epicoene* (1609) is a noisy farce of metropolitan fashion and frivolity; *The Alchemist* (1610) exhibits the conjurings and deceptions

The London scene in Jonson's plays

of clever London rogues; and *Bartholomew Fair* (1614) draws a rich portrait of city life parading through the annual fair at Smithfield, a vast panorama of a complete society. In these plays, fools and rogues are indulged to the very height of their daring, forcing upon the audience both criticism and admiration; the strategy leaves the audience to draw its own conclusions while liberating Jonson's wealth of exuberant comic invention, virtuoso skill with plot construction, and mastery of a language tumbling with detailed observation of London's multifarious ephemera. After 1616 Jonson abandoned the stage for the court, but, finding himself increasingly disregarded, he made a hard-won return to the theatres. The most notable of his late plays are popular in style: *The New Inn* (1629), which has affinities with the Shakespearean romance, and *A Tale of a Tub* (1633), which resurrects the Elizabethan country farce.

Marston and Middleton. Of Jonson's successors in city comedy, Francis Beaumont, in *The Knight of the Burning Pestle* (1607), amusingly insults the citizenry while ridiculing their taste for romantic plays. John Marston adopts so sharp a satirical tone that his plays in this genre frequently border on tragedy. All values are mocked by Marston's bitter and universal skepticism; his city comedy *The Dutch Courtezan* (1604), set in London, quotes a defense of libertinism from Montaigne. His tragicomedy *The Malcontent* (1604) is remarkable for its wild language and sexual and political disgust; Marston cuts the audience adrift from the moorings of reason by a dizzying interplay of parody and seriousness. Only in the city comedies of Thomas Middleton was Jonson's moral concern with greed and self-ignorance bypassed, for Middleton accepts the pursuit of money as, inevitably, the sole human absolute and presents buying and selling, usury, law, and the wooing of rich widows as the dominant modes of social interaction. His unprejudiced satire touches the actions of citizen and gentleman with equal irony and detachment; the only operative distinction is between fool and knave, and the sympathies of the audience are typically engaged on the side of wit, with the resourceful prodigal and dexterous whore. His characteristic form, used in *Michaelmas Terme* (1605) and *A Tricke to Catch the Old-One* (1606), was intrigue comedy, which enabled him to portray his society dynamically, as a mechanism in which each sex and class pursues its own selfish interests. He was thus concerned less to characterize the individual in depth than to examine the inequalities and injustices of the world that cause him to behave as he does. *The Roaring Girle* (*c.* 1608) and *A Chaste Maid in Cheapside* (1613) are the only Jacobean comedies to rival the comprehensiveness of *Bartholomew Fair,* but their social attitudes are opposed to Jonson's; the misbehaviour that Jonson condemned morally as "humours" or affectation Middleton understands as the product of circumstance.

Social concerns in Middleton's tragedies

Middleton's social concerns are also powerfully operative in his great tragedies, *Women Beware Women* (*c.* 1621) and *The Changeling* (1622), in which the moral complacency of men of rank is shattered by the dreadful violence they themselves have casually set in train, proving the answerability of all men for their actions despite the exemptions claimed for privilege and status. The hand of heaven is even more explicitly at work in the overthrow of the aristocratic libertine D'Amville in Cyril Tourneur's *Atheist's Tragedie* (*c.* 1611). Here the breakdown of old codes of deference before a progressive middle-class morality is strongly in evidence, and in *The Revenger's Tragedy* (1607), now generally attributed to Middleton, a scathing attack on courtly dissipation is reinforced by complaints about inflation and penury in the countryside at large. For more traditionally minded playwrights, new anxieties lay in the corrupt and sprawling bureaucracy of the modern court and in the political eclipse of the nobility before incipient royal absolutism. In Jonson's *Sejanus* (1603) Machiavellian statesmen abound, while George Chapman's *Bussy d'Ambois* (1604) and *Conspiracy of Charles, Duke of Byron* (1608) drew on recent French history to chart the collision of the magnificent but redundant heroism of the old-style aristocrat, whose code of honour had outlived its social function, with pragmatic arbitrary monarchy; Chapman doubtless had the career and fate of Essex in mind. The classic tragedies of state are John Webster's, with their dark Italian courts, intrigue and treachery, spies, malcontents, and informers. His *White Divel* (1612), a divided, ambivalent play, elicits sympathy even for a vicious heroine, since she is at the mercy of her deeply corrupt society; and the heroine in *The Duchess of Malfi* (1623) is the one decent and spirited inhabitant of her world, yet her noble death cannot avert the fearfully futile and haphazard carnage that ensues. As so often on the Jacobean stage, the challenge to the male-dominated world of power was mounted through the experience of its women.

Early Stuart drama. In the early Stuart period signs of a more polite drama, such as would prevail after 1660, were already beginning to appear in the comedies of fashionable manners written by John Fletcher and James Shirley, but even these playwrights lampooned courtiers and their overbearing ways. The traditions of a socially and politically critical theatre were carried down to the Civil War in the tragedies of John Ford (*'Tis Pitty Shee's a Whore,* 1633) and Philip Massinger (*Believe as You List,* 1631) and in comedies by Massinger (*A New Way to Pay Old Debts,* 1624; *The City Madam,* 1632) and Richard Brome (*The Antipodes,* 1638), which continued to probe at the tensions that were soon completely to undermine the basis of Stuart government. The outbreak of fighting in 1642 brought about the closing of the playhouses, but this was not because of any hostility by dramatists to politics or to change; rather, the crisis in which they were embroiled was one that had been the drama's continuing preoccupation for three generations.

EARLY STUART POETRY AND PROSE

In the early Stuart period the failure of consensus was dramatically announced in the political collapse of the 1640s and in the growing sociocultural divergences of the immediately preceding years. While it was still possible for the theatres to address the nation very much as a single audience, the court, with the baroque, absolutist style it encouraged in painting, masque, and panegyric, was becoming increasingly remote from the country at large and was regarded with justifiable distrust. In fact, a growing separation between polite and vulgar literature was to dispel many of the characteristic strengths of Elizabethan writing. Simultaneously, long-term intellectual changes were beginning to impinge on the status of poetry and prose. Sidney's defense of poetry, which maintained that poetry depicted what was ideally rather than actually true, was rendered redundant by the loss of agreement over transcendent absolutes; the scientist, the Puritan with his inner light, and the skeptic differed equally over the criteria by which truth or meaning was to be established. From the circle of Lord Falkland at Great Tew, which included poets such as Edmund Waller, Thomas Carew, and Sidney Godolphin, William Chillingworth argued that it was unreasonable for any individual to force his opinions onto any other, while Thomas Hobbes reached the opposite conclusion (in his *Leviathan,* 1651), that all must be as the state pleases. In this context, the old idea of poetry as a persuader to virtue fell obsolete, and the century as a whole witnessed a massive transfer of energy into new literary forms, particularly into the rationally balanced couplet, the autobiography, and the novel. At the same time, these influences were neither uniform nor consistent; Hobbes might repudiate the use of metaphor as senseless and ambiguous, yet his own prose is frequently enlivened by half-submerged metaphors.

Emergence of new literary forms

The Metaphysical poets. Writers responded to these conditions in different ways, and in poetry three types of practice may broadly be distinguished, which have been coupled with the names of Spenser, Jonson, and Donne. John Donne heads the tradition that Samuel Johnson typified for all time as the Metaphysicals; what unites them as a group is less the violent yoking of unlike ideas to which Johnson objected than that they were all poets of personal and individual feeling, responding to their time's pressures privately or introspectively (this very privateness, of course, was new; the period in general experienced a

massive trend toward contemplative or devotional verse).

Donne. Donne has been taken to be the apex of the 16th-century tradition of plain poetry, and certainly the love lyrics of his that parade their cynicism, indifference, and libertinism pointedly invert and parody the conventions of Petrarchan lyric, though no less than the Petrarchans he courts admiration for his poetic virtuosity. A "great haunter of plays" in his youth, he is always dramatic; his verse cultivates "strong lines," dissonance, and colloquiality. Thomas Carew praised him for exiling from poetry the "train of gods and goddesses"; what fills it instead is a dazzling battery of language and argument drawn from science, law and trade, court and city. Donne is the first London poet: his early satires and elegies are packed with the busy metropolitan milieu, and the songs and sonnets, which include his best writing, with their kaleidoscope of contradictory attitudes, ironies, and contingencies, are authentic to the modern phenomenon of urban living. Donne treats experience as relative, a matter of individual point of view; the personality is multiple, quizzical, and inconsistent, eluding definition. His love poetry is that of the frustrated careerist. By inverting normal perspectives and making the mistress "all states, and all princes, I, nothing else is," he belittles the public world, defiantly asserting the superior validity of his private experience, and frequently he erodes the traditional dichotomy of body and soul, outrageously praising the mistress in language reserved for platonic or religious contexts. The defiance is complicated, however, by a recurrent conviction of personal unworthiness that culminates in the *Anniversaries* (1611–12), two long commemorative poems written on the death of a patron's daughter. These expand into the classic statement of Jacobean melancholy, an intense meditation on the vanity of the world and the collapse of traditional certainties. Donne would, reluctantly, find respectability in a church career, but even his religious poems are torn between the same tense self-assertion and self-abasement that mark his secular poetry.

Donne's influence. Donne's influence was vast; the taste for wit and conceits reemerged in dozens of minor lyricists, among them courtiers such as Aurelian Townshend, William Habington, and William Cartwright and religious poets such as Francis Quarles and Henry King. The only true Metaphysical, in the sense of a poet with genuinely philosophical pretensions, was Edward Herbert (Lord Herbert of Cherbury), important as an early proponent of religion formulated by the light of reason. Donne's most interesting imitators were the three major religious poets—George Herbert, with his practical piety and richly domestic world, who substituted for Donne's tortured selfhood a humane, meditative assurance; the Roman Catholic Richard Crashaw, whose hymns introduced the sensuous ecstasies and effusions of the continental baroque; and Henry Vaughan, with his hermetic naturalism and mystical raptures.

In the context of the Civil War, however, Vaughan's and Crashaw's introspection begins to look like retreat, and when the satires of John Cleveland and the lyrics of Abraham Cowley take the Donne manner to extremes of paradox and vehemence, it suggests a loss of control in the face of political and social traumas. The one poet for whom metaphysical wit became a strategy for enforcing accommodations between conflicting allegiances was Donne's outstanding heir, Andrew Marvell. Marvell's finest writing is taut, extraordinarily dense and precise, uniquely combining a cavalier lyric grace with puritanical economy of statement. It seems to have been done at the time of greatest strain, in about 1650–53, and under the patronage of Sir Thomas Fairfax, parliamentarian general but opponent of the King's execution, whose retirement from politics to his country estate Marvell accorded qualified praise in "Upon Appleton House." His lyrics are poems of the divided mind, sensitive to all the major conflicts of their society—body against soul, action against retirement, experience against innocence, Oliver Cromwell against the King—but Marvell sustains the conflict of irreconcilables through paradox and wit rather than attempting to decide or transcend it. In this situation, irresolution has become a strength: in a poem like "An Horatian Ode upon Cromwell's Return from Ireland," which weighs the claims of King Charles and Cromwell, the poet's reserve was the only effective way of confronting the unprecedented demise of traditional structures of politics and morality.

Marvell

Jonson and the Cavalier poets. By contrast, the Jonsonian tradition was, broadly, that of social verse, written with a classical clarity and weight and deeply informed by ideals of civilized reasonableness, ceremonious respect, and inner self-sufficiency derived from Seneca; it is a poetry of publicly shared values and norms. Jonson's own verse was occasional; it addresses other individuals, distributes praise and blame, and promulgates sober and judicious ethical attitudes. His favoured forms were the ode, elegy, satire, epistle, and epigram, and they are always crafted as exactly articulated objects, achieving a classical symmetry and monumentality. For Jonson the plain style meant not colloquiality but labour, restraint, and control; a good poet had first to be a good man, and his verses lead his society toward an aristocratic ethic of gracious but responsible living. With the Cavalier poets who succeeded him, the element of urbanity and conviviality tended to loom larger; Robert Herrick was perhaps England's first poet to express impatience with the tediousness of country life. However, Herrick's "The Country Life" and "The Hock Cart" rival Jonson's "To Penshurst" as panegyrics to the Horatian ideal of the "good life," calm and retired, but Herrick's poems gain poignancy by their implied contrast with the disruptions of the Civil War. The courtiers Thomas Carew, Sir John Suckling, and Richard Lovelace developed a manner of ease and naturalness suitable to the world of gentlemanly pleasure in which they moved; Suckling's *A Session of the Poets* lists more than 20 wits then in town. The Cavalier poets were writing England's first vers de société, lyrics of compliments and casual liaisons, often cynical, occasionally obscene; this was a line to be picked up again after 1660, as was the heroic verse and attitudinizing drama of Jonson's successor as poet laureate, Sir William Davenant. A different contribution was the elegance and smoothness that came to be associated with Sir John Denham and Edmund Waller, whom Dryden named as the first exponents of "good writing." Waller's polite lyrics now seem rather insipid, but Denham's topographical poem "Cooper's Hill" (1641), a considerable work in its own right, is plainly an important precursor of the balanced Augustan couplet (as is the otherwise slight oeuvre of Lucius Cary, Viscount Falkland). The growth of Augustan gentility was further encouraged by work done on translations in mid-century, particularly by Sir Richard Fanshawe (*Il Pastor Fido,* 1647) and Thomas Stanley.

Continued influence of Spenser. Donne had shattered Spenser's leisurely ornamentation, and Jonson censured his archaic language, but the continuing regard for Spenser at this time was significant. Variants of the Spenserian stanza were used by the brothers Giles and Phineas Fletcher, the former in his long religious poem *Christs Victorie* (1610), which is also indebted to Josuah Sylvester's highly popular translations from the French Calvinist poet Guillaume du Bartas, the *Divine Weeks and Works* (1605). Similarly, Spenserian pastorals still flowed from the pens of William Browne (*Britannia's Pastorals,* 1613–16), George Wither (*The Shepherd's Hunting,* 1614), and Michael Drayton, who at the end of his life returned nostalgically to portraying an idealized Elizabethan golden age (*The Muses Elizium,* 1630). Nostalgia was a dangerous quality under the progressive and absolutist Stuarts; the taste for Spenser involved a respect for values—traditional, patriotic, and Protestant—that were popularly, if erroneously, linked with the Elizabethan past but thought to be disregarded by the new regime. These poets believed they had a spokesman at court in the heroic and promising Prince Henry, but his death in 1612 disappointed many expectations, intellectual, political, and religious, and this group in particular was forced further toward the puritanical position. Increasingly their pastorals and fervently Protestant poetry aligned them in opposition to a court of Cavalier wits and of suspiciously pro-Spanish and pro-Catholic sympathies in foreign affairs; so sharp became Wither's satires that he earned imprisonment and was lampooned by Ben Jonson in a court masque. The failure

Literary opposition at court

of the Stuarts to conciliate attitudes such as these was to be crucial to their inability to maintain the cohesion of the Elizabethan compromise in the next generation. The nearest affinities, both in style and substance, of John Milton's early poetry would be with the Spenserians; in *Areopagitica* (1644) Milton praised "our sage and serious poet Spenser" as "a better teacher than Scotus or Aquinas."

Effect of religion and science on early Stuart prose. Puritanism also had a powerful effect on early Stuart prose. The best-sellers of the period were godly manuals that ran to scores of editions, like Arthur Dent's *Plain Man's Pathway to Heaven* (25 editions by 1640) and Lewis Bayly's *Practice of Piety* (1611; some 50 editions followed), the two of which formed the meagre dowry of John Bunyan's first wife. Puritans preferred sermons in the plain style too, eschewing rhetoric for an austerely profitable treatment of doctrine, though equally some famous godly preachers, such as Henry Smith and Thomas Adams, believed it their duty to make the Word of God eloquent. The other shaping factor was the desire among scientists for a utilitarian prose that would accurately and concretely represent the relationship between words and things, without figurative luxuriance. This hope, repeatedly voiced in the 1640s and '50s, eventually bore fruit in the practice of the Royal Society (incorporated 1662), which decisively affected prose after the Restoration. Its impact on earlier prose, though, was limited; most early Stuart science was written in the baroque style.

Sir Francis Bacon

The impetus toward a scientific prose derived ultimately from Sir Francis Bacon, the towering intellect of the century, who charted a philosophical system well in advance of his generation and beyond his own powers to complete. In the *Advancement of Learning* (1605) and the *Novum Organum* (1620) Bacon visualized a great synthesis of knowledge, rationally and comprehensively ordered so that each discipline might benefit from the discoveries of the others. The two radical novelties of his scheme were his insight that there could be progress in learning, that the limits of knowledge were not fixed but could be pushed forward, and his inductive method, by which scientific principles were to be established by experimentation, beginning at particulars and working toward generalities, instead of working backward from preconceived systems. Bacon democratized knowledge at a stroke, removing the tyranny of authority and lifting scientific inquiry free of religion and ethics and into the domain of mechanically operating second causes (though he held that the perfection of the machine itself testified to God's glory). The implications for prose are contained in his statement in the *Advancement* that the preoccupation with words instead of matter was the first "distemper" of learning; his own prose, however, was far from plain. The level exposition of idea in the *Advancement* is underpinned by a tactful but firmly persuasive rhetoric; and the famous *Essayes* (1597; enlarged 1612, 1625) are shifting and elusive, teasing the reader toward unresolved contradictions and half-apprehended complications.

The *Essayes* are masterworks in the new Stuart genre of the prose of leisure, the reflectively aphoristic prose piece in imitation of the *Essais* of Montaigne. Lesser collections were published by Sir William Cornwallis (1600–01), Owen Felltham (1623), and Ben Jonson (his posthumous *Timber; or, Discoveries*). A related genre was the "character," a brief, witty description of a social or moral type, imitated from Theophrastus, and practiced first by Joseph Hall (*Characters of Vertues and Vices,* 1608) and later by Sir Thomas Overbury, John Webster, and Thomas Dekker. The best characters are John Earle's (*Microcosmographie,* 1628). Character-writing led naturally into the writing of biography; the chief practitioners of this genre were Thomas Fuller, who included brief sketches in *The Holy State* (1642; includes *The Profane State*), and Izaak Walton, the biographer of Donne, George Herbert, and Richard Hooker. Walton's hagiographies are entertaining, but he manipulated the facts shamelessly; his biographies seem lightweight when placed beside Fulke Greville's tragical and valedictory *Life of the Renowned Sir Philip Sidney (c.* 1610; published 1652). The major historical work of the period was Sir Walter Raleigh's unfinished *History of the World* (1614), with its rolling periods and sombre skepticism, written from the Tower during his disgrace. Raleigh's providential framework would recommend his *History* to Cromwell and Milton; King James found it "too saucy in censuring princes." Bacon's *History of the Raigne of King Henry the Seventh* (1622) belongs to a more secular, Machiavellian tradition, which valued history for its lessons in pragmatism.

Prose styles. The essayists and character writers initiated a reaction against the orotund flow of serious Elizabethan prose that has been variously described as metaphysical, anti-Ciceronian, or Senecan, but these terms are used vaguely to denote both the cultivation of a clipped, aphoristic prose style, curt to the point of obscurity, and a fashion for looseness, asymmetry, and open-endedness. The age's professional stylists were the preachers, and in the sermons of Lancelot Andrewes and John Donne the clipped style is used to crumble the preacher's exegesis into tiny, hopping fragments or to suggest a nervous, agitated restlessness. An extreme example of the loose style is Robert Burton's *Anatomy of Melancholy* (1621), a massive encyclopaedia of learning, pseudoscience, and anecdote strung around an investigation into human psychopathology. Burton's compendiousness, his fascination with excess, necessitated a style that was infinitely extensible; his successor was Sir Thomas Urquhart, whose translation of *Gargantua and Pantagruel* (1653) outdoes even Rabelais. In the *Religio Medici* (1635), *The Garden of Cyrus,* and *Hydriotaphia, Urne-buriall, or A discourse of the Sepulchrall Urnes Lately Found in Norfolk* (1658) of Sir Thomas Browne the loose style serves a mind delighting in paradox and unanswerable speculation, content with uncertainty because of its intuitive faith in ultimate assurance. Browne's majestic prose invests his confession of his belief and his antiquarian and scientific tracts alike with an almost Byzantine richness and melancholy.

Rise of popular journalism

These were all learned styles, Latinate and sophisticated, but the appearance in the 1620s of the first *corantos,* or courants (news books), generated by interest in the Thirty Years' War, heralded the great 17th-century shift from an elite to a mass readership, a change effected by the explosion of popular journalism that accompanied the political confusion of the 1640s. The search for new kinds of political order and authority generated an answering chaos of styles, as voices were heard that had hitherto been denied access to print. The radical ideas of educated political theorists like Thomas Hobbes and the republican James Harrington were advanced within the traditional decencies of polite (if ruthless) debate, but they spoke in competition with vulgar writers who deliberately breached the literary canons of good taste—Levellers, such as John Lilburne and Richard Overton, with their vigorously dramatic manner; Diggers, like Gerrard Winstanley with his call for a general *Law of Freedom* (1652); and Ranters, whose language and syntax were as disruptive as the libertinism they professed. The outstanding examples were Milton's tracts against the bishops (1641–42), which revealed an unexpected talent for scurrilous abuse and withering sarcasm. Milton's later pamphlets, on divorce, education, and free speech (*Areopagitica,* 1644) and in defense of tyrannicide (*The Tenure of Kings and Magistrates,* 1649), adopt a loosely Ciceronian sonorousness, but their language is plain and always intensely imaginative and absorbing.

Milton's view of the poet's role. Milton had a concept of the public role of the poet even more elevated, if possible, than Jonson's; he early declared his hope to do for his native tongue what "the greatest and choicest wits of Athens, Rome, or modern Italy" had done for theirs. But where Jonson's humanism had led him toward a classical absolutism, Milton's was crossed by a respect for the conscience acting in pursuance of those things that it, individually, knew were right; he wished to "contribute to the progress of real and substantial liberty; which is to be sought for not from without, but within." His early verse aligned him, poetically and politically, with the Spenserians: religious and pastoral odes; "Lycidas" (1637), a pastoral elegy that incidentally bewails the state of the church; and *Comus* (1634), a masque against "masquing," performed privately in the country and opposing a private

heroism in chastity and virtue to the courtly round of revelry and pleasure.

During the interregnum, between the execution of Charles I and the restoration of Charles II, Milton saw his role as the intellectual serving the state in a glorious cause; he devoted his energies to pamphleteering, and he became Oliver Cromwell's Latin secretary. But the republic of virtue failed to materialize; Milton's courageous voice was the last before the Restoration to propose *The Ready and Easy Way to Establish a Free Commonwealth* (1660), a desperate program for a permanent oligarchy of the puritan elect, intended to avert the return to royal slavery. His greatest achievements, *Paradise Lost, Paradise Regained,* and *Samson Agonistes,* did not appear until several years after the Restoration, but their roots are deep in the radical experience of the 1640s and '50s and in the ensuing transformations in politics and society. For Milton and his contemporaries, 1660 was a watershed that was to necessitate a complete rethinking of expectations and ideas and a corresponding reassessment of the literary language, traditions, and forms appropriate to the new age. (M.H.B.)

The Restoration

LITERARY REACTIONS TO THE POLITICAL CLIMATE

The restoration of Charles II in 1660 led many to a painful revaluation of the political hopes and millenarian expectations bred during two decades of civil war and republican government. With the return of an efficient censorship, ambitiously heterodox ideas in theology and politics that had found their way freely into print during the 1640s and '50s were once again denied publication. The experience of defeat needed time to be absorbed, and fresh strategies had to be devised to encounter the challenge of hostile times. Much caustic and libelous political satire was written during the reigns of Charles II and James II and (because printing was subject to repressive legal constrictions) circulated anonymously and widely in manuscript. Andrew Marvell, sitting as member of Parliament for Hull in three successive parliaments from 1659 to 1678, experimented energetically with this mode, and his *Last Instructions to a Painter* (written in 1667) achieves a control of a broad canvas and an alertness to apt detail and to the movement of masses of people that make it a significant forerunner of Alexander Pope's *Dunciad* (however divergent the two poets' political visions may be). Marvell also proved himself to be a dexterous, abrasive prose controversialist, comprehensively deriding the anti-Dissenter arguments of Samuel Parker (later bishop of Oxford) in *The Rehearsal Transpros'd* (1672, with a sequel in 1673) and providing so vivid an exposition of Whig suspicions of the restored monarchy's attraction to absolutism in *An Account of the Growth of Popery, and Arbitrary Government in England* (1677) that a reward of £100 was offered for revealing its author's identity.

Return of censorship

The defeated republicans. The greatest prose controversialist of the pre-1660 years, John Milton, did not return to that mode but, in his enforced retirement from the public scene, devoted himself to his great poems of religious struggle and conviction, *Paradise Lost* (1667) and *Paradise Regained* and *Samson Agonistes* (both 1671). Each, in its probing of the intricate ways in which God's design reveals itself in human history, can justly be read (in one of its dimensions) as a chastened but resolute response to the failure of a revolution in which Milton himself had placed great trust and hope.

Others of the defeated republicans set out to record their own or others' experiences in the service of what they called the "good old cause." Lucy Hutchinson, for example, composed, probably in the mid-1660s, her remarkable memoirs of the life of her husband, Colonel Hutchinson, the Parliamentarian commander of Nottingham during the Civil War. Edmund Ludlow, like Hutchinson one of the regicides, fled to Switzerland in 1660, where he compiled his own *Memoirs.* These were published only in 1698–99 after Ludlow's death, and the discovery in 1970 of part of Ludlow's own manuscript revealed that they were edited and rewritten by another hand before printing. Civil War testimony still had political applications in the last years of the century, but those who sponsored its publication judged that Ludlow's now old-fashioned, millenarian rhetoric should be suppressed in favour of a soberer commonwealthman's dialect. Some autobiographers themselves adjusted their testimony in the light of later developments. George Fox, the Quaker leader, for example, dictating his *Journal* to various amanuenses, dubiously claimed for himself an attachment to pacifist principles during the 1650s, whereas it was, in fact, only in 1661, in the aftermath of the revolution's defeat, that the peace principle became central to Quakerism. The *Journal* itself only reached print in 1694 (again, after its author's death) after revision by a group superintended by William Penn. Such caution suggests a lively awareness of the influence such a text could have in consolidating a sect's sense of its own identity and continuity.

John Bunyan

Writings of the Nonconformists. John Bunyan's *Grace Abounding* (1666), written while he was imprisoned in Bedford jail for nonconformity with the Church of England, similarly relates the process of his own conversion for the encouragement of his local, dissenter congregation. It testifies graphically to the force, both terrifying and consolatory, with which the biblical word could work upon the consciousness of a scantily educated, but overwhelmingly responsive, 17th-century believer. The form of *Grace Abounding* has numerous precedents in spiritual autobiography of the period, but with *The Pilgrim's Progress* (the first part of which appeared in 1678) Bunyan found himself drawn into a much more novel experiment, developing an ambitious allegorical narrative when his intent had been to write a more conventionally ordered account of the processes of redemption. The resulting work (with its second part appearing in 1684) combines a careful exposition of the logical structure of the Calvinist scheme of salvation with a delicate responsiveness to the ways in which his experience of his own world (of the life of the road, of the arrogance of the rich, of the rhythms of contemporary speech) can be deployed to render with a new vividness the strenuous testing the Christian soul must undergo. His achievement owes scarcely anything to the literary culture of his time, but his masterpiece has gained for itself a readership greater than that achieved by any other English 17th-century work with the exception of the King James Bible. Two other of his works, though lesser in stature, are especially worth reading: *The Life and Death of Mr. Badman* (1680), which, with graphic local detail, remorselessly tracks the sinful temptations of everyday life, and *The Holy War* (1682), a grandiose attempt at religious mythmaking interlaced with contemporary political allusions.

Richard Baxter, a Nonconformist cleric who, although enduring persecution after 1660, was by instinct and much of his practice a reconciler, published untiringly on religious issues. He wrote, soon after the death of his wife, the moving *Breviate* (1681), a striking combination of exemplary narrative and unaffectedly direct reporting of the nature of their domestic life. His finest work, however, is the *Reliquiae Baxterianae* (published, five years after his death, in 1696), an autobiography that is also an eloquent defense of the Puritan impulse in the 17th-century Christian tradition.

Samuel Butler

The voice of anti-Puritan reaction can be heard in Samuel Butler's extensive mock-heroic satire *Hudibras* (published in three installments between 1662 and 1678). This was a massively popular work, with an influence stretching well into the 18th century (when Samuel Johnson, for example, greatly admired it and William Hogarth illustrated some scenes from it). It reads partly as a consummately destructive act of revenge upon those who had usurped power in the previous two decades, but although it is easy to identify what *Hudibras* opposes, it is difficult to say what, if anything, it affirms. Although much admired by Royalist opinion, it shows no wish to celebrate the authority or person restored in 1660, and its brazenly undignified use of rhyming tetrameters mirrors, mocks, and lacerates rooted human follies far beyond the power of one political reversal to obliterate. A comparable sardonic disenchantment is apparent in Butler's shorter verse satires and in his incisive and densely argued collection of prose *Characters.*

Writings of the Royalists. Royalists also resorted to biography and autobiography to record their experiences of defeat and restoration. Three of the most intriguing are by women: Margaret, duchess of Newcastle's life of her husband (1667) and the memoirs of Ann, Lady Fanshawe, and of Anne, Lady Halkett (both written in the late 1670s but not published in a fairly complete form until, respectively, 1829 and 1875). But incomparably the richest account of those years is *The History of the Rebellion and Civil Wars in England* by Edward Hyde, earl of Clarendon. The work was begun in exile during the late 1640s and was revised and completed in renewed exile after Clarendon's fall from royal favour in 1667. Clarendon was a close adviser to two kings, and his intimacy with many of the key events is unrivaled. Though his narrative is inevitably partisan, the ambitious range of his analysis and his mastery of character portraiture make the *History* an extraordinary accomplishment. His autobiography, which he also wrote during his last exile, gravely chronicles the transformations of the gentry world between the 1630s and '60s.

In 1660 feeling in the country ran strongly in favour of the Church of England, persecution having confirmed in many a deep affection for Anglican rites and ceremonies. The reestablished church, accepting for itself the role of staunch defender of kingly authority, tended to eschew the exploration of ambitious and controversial theological issues and devoted itself instead to expounding codes of sound moral conduct. It was an age of eminent preachers (including Robert South, Isaac Barrow, Edward Stillingfleet, and John Tillotson) and of keen interest in the art of preaching. In conscious reaction against the obscurantist dialects judged typical of the sects, a plain and direct style of sermon oratory was favoured. Thus, in his funeral sermon on Tillotson in 1694, Gilbert Burnet praised the Archbishop because he "said what was just necessary to give clear Ideas of things, and no more" and "laid aside all long and affected Periods."

Role of the Church of England

MAJOR GENRES AND MAJOR AUTHORS OF THE PERIOD

A comparable preference for an unembellished and perspicuous use of language is apparent in much of the nontheological literature of the age. Thomas Sprat, in his propagandizing *History of the Royal Society of London* (1667), and with the needs of scientific discovery in mind, also advocated "a close, naked natural way of speaking, positive expressions, clear senses, a native easiness." Sprat's work and a series of books by Joseph Glanvill, beginning with *The Vanity of Dogmatizing* (1661), argued the case for an experimental approach to natural phenomena against both the old scholastic philosophy and general conservative prejudice. That a real struggle was involved can be seen from the invariably disparaging attitude of contemporary satires to the labours of the Royal Society's enthusiasts (see, for instance, Samuel Butler's "The Elephant in the Moon," probably written in 1670–71, and Thomas Shadwell's *The Virtuoso,* 1676)—a tradition to be sustained later by Swift and Pope. But evidence of substantial achievement for the new generation of explorers was being published throughout the period, in, for example, Robert Boyle's *Sceptical Chymist* (1661), Robert Hooke's *Micrographia* (1665), John Ray's *Historia Plantarum* (in three volumes, 1686–1704), and, above all, Isaac (later Sir Isaac) Newton's *Philosophiae Naturalis Principia Mathematica* (1687).

Chroniclers. The Restoration, in its turn, bred its own chroniclers. Anthony à Wood, the Oxford antiquarian, made in his *Athenae Oxonienses* (1691–92) the first serious attempt at an English biographical dictionary. His labours were aided by John Aubrey, whose own unsystematic but enticing manuscript notes on the famous have been published in modern times under the title *Brief Lives.* After 1688 secret histories of the reigns of Charles II and James II were popular, of which the outstanding instance, gossipy but often reliable, is the *Memoirs of the Count Grammont,* compiled in French by Anthony Hamilton and first translated into English in 1714. A soberer but still free-speaking two-volume *History of My Own Time* (published posthumously, 1724–34) was composed by the industrious Gilbert Burnet, bishop of Salisbury from 1689. In the last months of the life of the court poet John Wilmot, 2nd earl of Rochester, Burnet had been invited to attend him, and in *Some Passages of the Life and Death of John, Earl of Rochester* (1680) he offered a fascinating account of their conversations as the erstwhile rake edged toward a rapprochement with the faith he had spurned.

A sparer, more finely focused prose was written by George Savile, 1st marquess of Halifax, who, closely involved in the political fray for 35 years, but remaining distrustful of any simple party alignments, wrote toward the end of his life a series of thoughtful, wryly observant essays, including *The Character of a Trimmer* (circulated in manuscript in late 1684 or very early 1685), *A Letter to a Dissenter* (published clandestinely in 1687), and *A Character of King Charles the Second* (written after about 1688). He also composed for his own daughter *The Lady's New-Year's-Gift; or, Advice to a Daughter* (1688), in which he anatomizes, with a sombre but affectionate wit, the pitfalls awaiting a young gentlewoman in life, especially in marriage.

Diarists. Two great diarists are among the most significant witnesses to the development of the Restoration world. Both possessed formidably active and inquisitive intelligences. John Evelyn was a man of some moral rectitude and therefore often unenamoured of the conduct he observed in court circles; but his curiosity was insatiable, whether the topic in question happened to be Tudor architecture, contemporary horticulture, or the details of sermon rhetoric. Samuel Pepys, whose diary, unlike Evelyn's, covers only the first decade of the Restoration, was the more self-scrutinizing of the two, constantly mapping his own behaviour with an alert and quizzical eye. Though not without his own moral inhibitions and religious gravity, Pepys immersed himself more totally than Evelyn in the new world of the 1660s, and it is he who gives the more resonant and idiosyncratic images of the changing London of the time.

The court wits. Among the subjects for gossip in London the group known as the "court wits" held a special place. Their conduct of their lives provoked censure from many, but among them were poets of some distinction, who drew upon the example of gentlemen-authors of the preceding generation (especially Sir John Suckling, Abraham Cowley, and Edmund Waller, the last two of whom themselves survived into the Restoration and continued to write impressive verse). The court wits' best works are mostly light lyrics, for example, Sir Charles Sedley's "Not, Celia, that I juster am" or Charles Sackville, earl of Dorset's "Dorinda's sparkling wit, and eyes." One of their number, the previously mentioned John Wilmot, earl of Rochester, possessed, however, a wider range and richer talent. Though some of his surviving poetry is in the least ambitious sense occasional work, he also produced writing of great force and authority, including a group of lyrics (for example, "All my past life is mine no more" and "An age in her embraces past") that, in psychological grasp and limpid deftness of phrasing, are among the finest of the century. He also wrote the harsh and scornfully dismissive *Satire Against Reason and Mankind* (probably before 1676) and experimented ingeniously with various forms of verse satire on contemporary society. The most brilliant of these, *A Letter from Artemisia in the Town, to Chloë in the Country* (written about 1675), combines a shrewd ear for currently fashionable idioms with a Chinese box structure that masks the author's own thoughts. Rochester's determined use of strategies of indirection anticipates Swift's tactics as an ironist.

John Oldham, a young schoolmaster, received encouragement as a poet from Rochester. His career, like his patron's, was to be cut short by an early death (in 1683, at age 30); but of his promise there can be no doubt. His *Satires upon the Jesuits* (1679–81), written during the Popish Plot, makes too unrelenting use of a rancorous, hectoring tone, but his development of the possibilities (especially satiric) of the "imitation" form, already explored by Rochester in, for example, *An Allusion to Horace* (written 1675–76), earns him an honourable place in the history of a mode that Pope was to put to such dazzling use. His imitation of the ninth satire of Horace's first

book exemplifies the agility and tonal resource with which Oldham could adapt a classical original to, and bring its values to bear upon, Restoration experience.

A poet who found early popularity with Restoration readers is Charles Cotton, whose *Scarronides* (1664–65), travesties of books one and four of Virgil's *Aeneid,* set a fashion for poetical burlesque. He is valued today, however, for work that attracted less contemporary interest but was to be admired by Wordsworth, Coleridge, and Charles Lamb. The posthumous *Poems on Several Occasions* (1689) includes deft poetry of friendship and love written with the familiar, colloquial ease of the Cavalier tradition and carefully observed, idiosyncratically executed descriptions of nature. He also added a second part to his friend Izaak Walton's *Compleat Angler* in 1676. A writer whose finest work was unknown to his contemporaries, much of it having been published only during the 20th century, is the poet and mystic Thomas Traherne. Influenced by the Hermetic writings and the lengthy Platonic tradition, he wrote, with extreme transparency of style, out of a conviction of the original innocence and visionary illumination of infancy. His poetry, though uneven, contains some remarkable writing, but his richest achievements are perhaps to be found in the prose *Centuries of Meditations* (first published in 1908).

Dryden. A poetic accomplishment of quite another order is that of John Dryden. He was 29 years old when Charles II returned from exile, and little writing by him survives from before that date. But for the remaining 40 years of his life he was unwearyingly productive, responding to the challenges of an unstable world with great formal originality and a mastery of many poetic styles. He

Dryden's commentary on public life

was profoundly a poet of the public domain, but the ways in which he addressed himself to the issues of the day varied greatly in the course of his career. Thus, his poem to celebrate the Restoration itself, *Astraea Redux* (1660), invokes Roman ideas of the return of a golden age under Augustus Caesar in order to encourage similar hopes for England's future; whereas in 1681 the Exclusion Crisis (the attempt to exclude Charles II's brother James, a Roman Catholic, from succeeding to the throne) drew from Dryden one of his masterpieces, *Absalom and Achitophel,* in which the Old Testament story of King David, through an ingenious mingling of heroic and satiric tones, is made to shadow and comment decisively upon the current political confrontation. Another of his finest inventions, *Mac Flecknoe* (written mid-1670s, published 1682), explores, through agile mock-heroic fantasy, the possibility of a world in which the profession of humane letters has been thoroughly debased through the unworthiness of its practitioners. The 1680s also saw the publication of two major religious poems: *Religio Laici or a Laymans Faith* (1682), in which he uses a plain style to handle calmly the basic issues of faith, and *The Hind and the Panther* (1687), in which an elaborate allegorical beast fable is deployed to trace the history of animosities between Anglicanism and Roman Catholicism. In the Revolution of 1688 Dryden stayed loyal to the Catholicism to which he had been converted a few years earlier and thus lost his public offices. Financial need spurred him into even more literary activity thereafter, and his last years produced immensely skilled translations of Juvenal, Persius, and Virgil and handsome versions of Boccaccio and Chaucer, as well as further fine original poetry.

Dryden as critic

Dryden was also, in Samuel Johnson's words, the father of English criticism. Throughout his career he wrote extensively on matters of critical precept and poetic practice. Such sustained effort for which there was no precedent presumed the possibility of an interested audience but also contributed substantially to the creation of one. His tone is consistently exploratory and undogmatic. He writes as a working author, with an eye to problems he has himself faced, and is skeptical of theoretical prescriptions that threaten to become straitjackets for the poet or the critic. His discussion of Ben Jonson's *Epicoene, or The Silent Woman* in *Of Dramatick Poesie, an Essay* (1668) is remarkable as the first extended analysis of an English play, and his *Discourse Concerning the Origin and Progress of Satire* (1693) and the preface to the *Fables Ancient and Modern* (1700) both contain detailed commentary of the highest order.

A contrary critical philosophy was espoused by Thomas Rymer, an adherent of the most rigid neoclassical notions of dramatic decorum, who surveyed the pre-1642 English drama in *Tragedies of the Last Age* (1678) and *A Short View of Tragedy* (1693) and found it wanting. His zealotry reads unattractively today, but Dryden was impressed by him, if disinclined to accept his judgments without protest. In due course the post-1660 playwrights were to find their own scourge in Jeremy Collier, whose *Short View of the Immorality and Profaneness of the English Stage* (1698) comprehensively indicted the Restoration stage tradition. The theoretical frame of Collier's tract is crude, but his strength lay in his dogged citation of evidence from published play texts, especially when the charge was blasphemy, a crime still liable to stiff penalties in the courts. Even so clever a man as William Congreve was left struggling when attempting to deny in print the freedoms he had allowed his wit.

Drama by Dryden and others. Characteristically, Dryden, as dramatist, experimented vigorously in all the popular stage modes of the day, exploring the possibilities of the rhymed heroic play in the 1660s and early 1670s and producing some distinguished tragic writing in *All for Love* (1677) and *Don Sebastian* (1689); but his greatest achievement, *Amphitryon* (1690), is a comedy. In this he was typical of his age. Though there were individual successes in tragedy (especially Thomas Otway's *Venice Preserved,* 1682, and Nathaniel Lee's *Lucius Junius Brutus,* 1680), the splendour of the Restoration theatre lies in its comic creativity. Several generations of dramatists contributed to that wealth. In the 1670s the most original work can be found in Sir George Etherege's *Man of Mode* (1676), William Wycherley's *Country-Wife* (1675) and *Plain-Dealer* (1676), and Aphra Behn's two-part *Rover* (1677, 1681). Commentary has often claimed to detect a disabling repetitiveness in even the best Restoration comic invention, but an attentive reading of *The Country-Wife* and *The Man of Mode* will reveal how firmly the two authors, close acquaintances, have devised dramatic worlds significantly dissimilar in atmosphere that set distinctive challenges for their players. The disturbed years of the Popish Plot produced comic writing of matching mood, especially in Otway's abrasive *Soldier's Fortune* (1680) and Lee's extraordinary variation on the Madame de La Fayette novella, *The Princess of Cleve* (1681–82). After the Revolution of 1688 a series of major comedies hinged on marital dissension and questions (not unrelated to contemporary political traumas) of contract, breach of promise, and the nature of authority. These include, in addition to *Amphitryon,* Thomas Southerne's *Wives Excuse* (1691), Sir John Vanbrugh's *Relapse* (1696) and *Provok'd Wife* (1697), and George Farquhar's *Beaux Stratagem* (1707). These years also saw the premieres of Congreve's four comedies and one tragedy, climaxing with his masterpiece, *The Way of the World* (1700), a brilliant combination of intricate plotting and incisively humane portraiture. The pressures brought upon society at home by continental wars against the French also began to make themselves felt, the key text here being Farquhar's *Recruiting Officer* (1706), in which the worlds of soldier and civilian are placed in suggestive proximity.

Creativity in comic Restoration theatre

After 1710 contemporary writing for the stage waned in vitality. The 18th century is a period of great acting and strong popular enthusiasm for the theatre, but only a few dramatists (Gay, Fielding, Goldsmith, and Sheridan) achieved writing of a quality to compete with their predecessors' best, and even a writer of Richard Brinsley Sheridan's undeniable resource produced in his best plays—*The Rivals* (1775), *The School for Scandal* (1777), and *The Critic* (1779)—work that seems more like a technically ingenious, but cautious, rearrangement of familiar materials than a truly innovative contribution to the corpus of English comic writing for the stage. A number of the Restoration masterpieces, however, continued to be performed well into the new century, and the influence of this comic tradition was also strongly apparent in satiric poetry and the novel in the decades that followed.

Locke. One other late 17th-century figure with a formidable influence in the 18th century demands consideration: the philosopher John Locke. His *Essay Concerning Human Understanding* (1690) rejects a belief in innate ideas and argues that the mind at birth is a tabula rasa. Experience of the world can only be accumulated through the senses, which are themselves prone to unreliability. The *Essay,* cautiously concerned to define the exact limits of what the mind can truly claim to know, threw exciting new light on the workings of human intelligence and stimulated further debate and exploration through the fertility of its suggestions—for example, about the way in which ideas come to be associated. Locke was equally influential on political thought. He came from Puritan stock and was closely linked during the Restoration with leading Whig figures, especially the most controversial of them all, the Earl of Shaftesbury. His *Two Treatises of Government* (published in 1690, but mainly written during the Exclusion Crisis 10 years earlier) asserts the right of resistance to unjust authority and, in the last resort, of revolution. To establish this he had to think radically about the origins of civil society, the mutual obligations of subjects and rulers, and the rights of property. The resulting work became the crucial reference point from which subsequent debate took its bearings.

The 18th century

PUBLICATION OF POLITICAL LITERATURE

The expiry of the Licensing Act in 1695 halted state censorship of the press. During the next 20 years there were to be 10 general elections. These two factors combined to produce an enormous growth in the publication of political literature. Senior politicians, especially Robert Harley, saw the potential importance of the pamphleteer in wooing the support of a wavering electorate, and numberless hack writers produced copy for the presses. Richer talents also played their part. Harley, for instance, instigated Daniel Defoe's industrious work on the *Review* (1704–13), which consisted, in essence, of a regular political essay defending, if often by indirection, current governmental policy. He also secured Jonathan Swift's polemical skills for contributions to *The Examiner* (1710–11). Swift's most ambitious intervention in the paper war, again overseen by Harley, was *The Conduct of the Allies* (1711), a devastatingly lucid argument against any further prolongation of the War of the Spanish Succession. Writers like Defoe and Swift did not confine themselves to straightforward discursive techniques in their pamphleteering but experimented deftly with mock forms and invented personae to carry the attack home. According to contemporary testimony, Defoe's *Shortest-Way with the Dissenters* (1702) so brilliantly sustained its impersonation of a High Church extremist, its alleged narrator, that it was at first mistaken for the real thing. This avalanche of political writing whetted the contemporary appetite for reading matter generally and, in the increasing sophistication of its ironic and fictional maneuvers, assisted in preparing the way for the astonishing growth in popularity of narrative fiction during the subsequent decades.

Contribution to political reviews

Political journalism. After Defoe's *Review* the great innovation in periodical journalism came with the achievements of Richard Steele and Joseph Addison in *The Tatler* (1709–11) and then *The Spectator* (1711–12). In a familiar, easily approachable style they tackled a great range of topics, from politics to fashion, from aesthetics to the development of commerce. They aligned themselves with those who wished to see a purification of manners after the laxity of the Restoration and wrote extensively, with descriptive and reformative intent, about social and family relations. Their political allegiances were Whig, and in their creation of Sir Roger de Coverley they painted a wry portrait of the landed Tory squire as likable, possessed of good qualities, but feckless and anachronistic. Contrariwise, they spoke admiringly of the positive and honourable virtues bred by a healthy, and expansionist, mercantile community. Addison, the more original of the two, was an adventurous literary critic who encouraged esteem for the ballad through his enthusiastic account of *Chevy-Chase,* wrote a thoughtful and probing examen of *Paradise Lost,* and hymned the pleasures of the imagination in a series of papers deeply influential on 18th-century thought. The success with which Addison and Steele established the periodical essay as a prestigious form can be judged by the fact that they were to have more than 300 imitators before the end of the century. The awareness of their society and curiosity about the way it was developing, which they encouraged in their eager and diverse readership, left its mark on much subsequent writing.

Major political writers. *Pope.* Alexander Pope contributed to *The Spectator* and moved for a time in Addisonian circles; but from about 1711 onward his more influential friendships were with Tory intellectuals. His early verse shows a dazzling precocity, his *Essay on Criticism* (1711) combining ambition of argument with great stylistic assurance and *Windsor-Forest* (1713) achieving an ingenious, late Stuart variation on the 17th-century mode of topographical poetry. The mock-heroic *Rape of the Lock* (final version published in 1714) is an astonishing feat, marrying a rich range of literary allusiveness and a delicately ironic commentary upon the contemporary social world with a potent sense of suppressed energies threatening to break through the civilized veneer. That he could also write successfully in a more plaintive mode is shown by "Eloisa to Abelard" (1717), which, modeled on Ovid's heroic epistles, enacts with moving force Eloisa's struggle to reconcile grace with nature, virtue with passion. But the prime focus of his labours between 1713 and 1720 was his energetically sustained and scrupulous translation of Homer's *Iliad* (to be followed by the *Odyssey* in the mid-1720s). From that decade onward his view of the transformations wrought in Robert Walpole's England by economic individualism and opportunism grew increasingly embittered and despairing. In this he was following a common Tory trend, epitomized most trenchantly by the writings of his friend, the politician Henry St. John, 1st Viscount Bolingbroke. Pope's *Essay on Man* (1733–34) was a grand systematic attempt to buttress the notion of a God-ordained, perfectly ordered, all-inclusive hierarchy of created things. But his most probing and startling writing of these years comes in the four *Moral Essays* (1731–35), the series of Horatian imitations, and the final four-book version of *The Dunciad* (1743), in which he turns to anatomize with outstanding imaginative resource the moral anarchy and perversion of once-hallowed ideals he sees as typical of the commercial society in which he must perforce live.

Pope's *Rape of the Lock*

Thomson, Prior, and Gay. James Thomson also sided with the opposition to Walpole, but his poetry sustained a much more optimistic vision. In *The Seasons* (first published as a complete entity in 1730 but then massively revised and expanded until 1746) Thomson meditated upon, and described with fascinated precision, the phenomena of nature. He brought to the task a vast array of erudition and a delighted absorption in the discoveries of post-civil war, especially Newtonian, science, from whose vocabulary he borrowed freely. The image he developed of man's relationship to, and cultivation of, nature provided a buoyant portrait of the achieved civilization and wealth that ultimately derive from them and that, in his judgment, contemporary England enjoyed. The diction of *The Seasons* has many Miltonian echoes. In *The Castle of Indolence* (1748) Thomson's model is Spenserian, and its wryly developed allegory lauds the virtues of industriousness and mercantile achievement.

A poet who, at his best, chose a less ambitious song to sing is Matthew Prior, a diplomat and politician of some distinction, who essayed graver themes in *Solomon on the Vanity of the World* (1718), a disquisition on the vanity of human knowledge, but who also wrote some of the most direct and coolly elegant love poetry of the period. Prior's principal competitor as a writer of light verse was John Gay, whose *Trivia: or, the Art of Walking the Streets of London* (1716) catalogues the dizzying diversity of urban life through a dexterous burlesque of Virgil's *Georgics.* His *Fables,* particularly those in the 1738 collection, contain sharp, subtle writing, and his work for the stage, especially in *The What D'Ye Call It* (1715), *Three Hours After Mar-*

riage (1717; written with John Arbuthnot and Pope), and *The Beggar's Opera* (1728), shows a sustained ability to breed original and vital effects from witty generic cross-fertilization.

Swift. Swift, who also wrote verse of high quality throughout his career, like Gay favoured octosyllabic couplets and a close mimicry of the movement of colloquial speech. His technical virtuosity allowed him to switch assuredly from poetry of great destructive force to the intricately textured humour of *Verses on the Death of Dr. Swift* (completed in 1732; published 1739) and to the delicate humanity of his poems to Stella. But his prime distinction is, of course, as the greatest prose satirist in the English language. His period as secretary to the distinguished man of letters, Sir William Temple, gave him the chance to extend and consolidate his reading, and his first major work, *A Tale of a Tub* (1704), deploys its author's learning to chart the anarchic lunacy of its supposed creator, a Grub Street hack, whose solipsistic "modern" consciousness possesses no respect for objectivity, coherence of argument, or inherited wisdom from Christian or classical tradition. Techniques of impersonation were central to Swift's art thereafter. The *Argument Against Abolishing Christianity* (1708), for instance, offers brilliant ironic annotations on the "Church in Danger" controversy through the carefully assumed voice of a "nominal" Christian. That similar techniques could be adapted to serve specific political goals is demonstrated by "The Drapier's Letters" (1724–25), part of a successful campaign to prevent the imposition of a new, and debased, coinage on Ireland. Swift had hoped for preferment in the English church, but his destiny lay in Ireland, and the ambivalent nature of his relationship to that country and its inhabitants provoked some of his most demanding and exhilarating writing—above all, *A Modest Proposal* (1729), in which the ironic use of an invented persona achieves perhaps its most extraordinary and mordant development. His most wide-ranging satiric work, however, is also his most famous, *Gulliver's Travels* (1726). Swift grouped himself with Pope and Gay in hostility to the Walpole regime and the Hanoverian court, and that preoccupation leaves its mark on this work. But *Gulliver's Travels* also hunts larger prey. At its heart is a radical critique of human nature in which subtle ironic techniques work to part the reader from any comfortable preconceptions and challenge him to rethink from first principles his notions of man.

Swift's major works

Shaftesbury and others. More consoling doctrine was available in the popular writings of Anthony Ashley Cooper, 3rd earl of Shaftesbury, which were gathered in his *Characteristicks of Men, Manners, Opinions, Times* (1711). Although Shaftesbury had been tutored by Locke, he dissented from the latter's rejection of innate ideas and posited that man is born with a moral sense that is closely associated with his sense of aesthetic form. The tone of Shaftesbury's essays is characteristically idealistic, benevolent, gently reasonable, and unmistakably aristocratic. His optimism was buffeted by Bernard de Mandeville, whose *Fable of the Bees* (1714–29), which includes "The Grumbling Hire" (1705), takes a closer look at early capitalist society than Shaftesbury was prepared to do. Mandeville stressed the indispensable role played by the ruthless pursuit of self-interest in securing society's prosperous functioning. He thus favoured an altogether harsher view of man's natural instincts than Shaftesbury did and used his formidable gifts as a controversialist to oppose the various contemporary hypocrisies, philosophical and theological, that sought to deny the truth as he saw it. He was, in his turn, the target of acerbic rebukes by, among others, William Law, John Dennis, and Francis Hutcheson. George Berkeley, who criticized both Mandeville and Shaftesbury, set himself against what he took to be the age's irreligious tendencies and the obscurantist defiance by some of his philosophical forbears of the truths of common sense. His *Treatise Concerning the Principles of Human Knowledge* (1710) and *Three Dialogues Between Hylas and Philonous* (1713) continued the 17th-century debates about the nature of human perception, to which Descartes and Locke had contributed. The extreme lucidity and elegance of his style contrast markedly with the more effortful, but intensely earnest, prose of Joseph Butler's *Analogy of Religion* (1736), which also seeks to confront contemporary skepticism and ponders scrupulously the bases of man's knowledge of his creator. In a series of works beginning with *A Treatise of Human Nature* (1739–40), David Hume identified himself as a key spokesman for ironic skepticism and probed uncompromisingly the human mind's propensity to work by sequences of association and juxtaposition rather than by reason. Edmund Burke's *Philosophical Enquiry into the Origin of Our Ideas of the Sublime and Beautiful* (1757) merged psychological and aesthetic questioning by hypothesizing that the spectator's or reader's delight in the sublime depended upon a sensation of pleasurable pain. An equally bold assumption about human psychology—in this case, that man is an ambitious, socially oriented, product-valuing creature—lies at the heart of Adam Smith's masterpiece of laissez-faire economic theory, *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776).

THE NOVEL

The major novelists. *Defoe.* Such ambitious debates on society and human nature ran parallel with the explorations of a literary form finding new popularity with a large audience, the novel. Defoe, for example, fascinated by any intellectual wrangling, was always willing (amid a career of unwearying activity) to publish his own views on the matter currently in question, be it economic, metaphysical, educational, or legal. His lasting distinction, though earned in other fields of writing than the disputative, is constantly underpinned by the generous range of his curiosity. Only someone of his catholic interests could have sustained, for instance, the superb *Tour Thro' the Whole Island of Great Britain* (1724–27), a vivid, county-by-county review and celebration of the state of the nation. He brought the same diversity of enthusiasms into play in writing his novels. The first of these, *Robinson Crusoe* (1719), an immediate success at home and on the Continent, is a unique fictional blending of the traditions of Puritan spiritual autobiography with an insistent scrutiny of the nature of man as social creature and an extraordinary ability to invent a sustaining modern myth. *A Journal of the Plague Year* (1722) displays enticing powers of self-projection into a situation of which Defoe can only have had experience through the narrations of others, and both *Moll Flanders* (1722) and *Roxana* (1724) lure the reader into puzzling relationships with narrators the degree of whose own self-awareness is repeatedly and provocatively placed in doubt.

Defoe's major works

Richardson. The enthusiasm prompted by Defoe's best novels demonstrated the growing readership for innovative prose narrative. Samuel Richardson, a prosperous London printer, was the next major author to respond to the challenge. His *Pamela: or, Virtue Rewarded* (1740, with a less happy sequel in 1741), using (like all Richardson's novels) the epistolary form, tells a story of an employer's attempted seduction of a young servant woman, her subsequent victimization, and her eventual reward in virtuous marriage with the penitent exploiter. Its moral tone is self-consciously rigorous and proved highly controversial. Its main strength lies in the resourceful, sometimes comically vivid imagining of the moment-by-moment fluctuations of the heroine's consciousness as she faces her ordeal. Pamela herself is the sole letter writer, and the technical limitations are strongly felt, though Richardson's ingenuity works hard to mitigate them. But Pamela's frank speaking about the abuses of masculine and gentry power sounds the skeptical note more radically developed in Richardson's masterpiece, *Clarissa: or, the History of a Young Lady* (1747–48), which has a just claim to being considered the most reverberant and moving tragic fiction in the English novel tradition. *Clarissa* uses multiple narrators and develops a profoundly suggestive interplay of opposed voices. At its centre is the taxing soul debate and eventually mortal combat between the aggressive, brilliantly improvisatorial libertine Lovelace and the beleaguered Clarissa, maltreated and abandoned by her family but abiding sternly loyal to her own inner sense of probity. The tragic consummation that grows from this

involves an astonishingly ruthless testing of the psychological natures of the two leading characters. After such intensities, Richardson's final novel, *The History of Sir Charles Grandison* (1753–54), is perhaps inevitably a less ambitious, cooler work, but its blending of serious moral discussion and a comic ending ensured it an influence on his successors, especially Jane Austen.

Fielding. Henry Fielding turned to novel writing after a successful period as a dramatist, during which his most popular work had been in burlesque forms. His entry into prose fiction was also in that mode. *An Apology for the Life of Mrs. Shamela Andrews* (1741), a travesty of Richardson's *Pamela,* transforms the latter's heroine into a predatory fortune hunter who cold-bloodedly lures her booby master into matrimony. Fielding continued his quarrel with Richardson in *The History of the Adventures of Joseph Andrews* (1742), which also uses *Pamela* as a starting point but which, developing a momentum of its own, soon outgrows any narrow parodic intent. His hostility to Richardson's sexual ethic notwithstanding, Fielding was happy to build, with a calm and smiling sophistication, on the growing respect for the novel to which his antagonist had so substantially contributed. In *Joseph Andrews* and *The History of Tom Jones, a Foundling* (1749) Fielding openly brought to bear upon his chosen form a battery of devices from more traditionally reputable modes (including epic poetry, painting, and the drama). This is accompanied by a flamboyant development of authorial presence. Fielding the narrator buttonholes the reader repeatedly, airs critical and ethical questions for the reader's delectation, and urbanely discusses the artifice upon which his fiction depends. In the deeply original *Tom Jones* especially, this assists in developing a distinctive atmosphere of self-confident magnanimity and candid optimism. His fiction, however, can also cope with a darker range of experience. *The Life of Mr. Jonathan Wild the Great* (1743), for instance, uses a mock-heroic idiom to explore a derisive parallel between the criminal underworld and England's political elite, and *Amelia* (1751) probes with sombre precision images of captivity and situations of taxing moral paradox.

Authorial presence in Fielding's novels

Smollett. Tobias Smollett had no desire to rival Fielding as a formal innovator, and his novels consequently tend to be rather ragged assemblings of disparate incidents. But, although uneven in performance, all of them include extended passages of real force and idiosyncracy. His freest writing is expended on grotesque portraiture in which the human is reduced to fiercely energetic automatism. Smollett can also be a stunning reporter of the contemporary scene, whether the subject be a naval battle or the gathering of the decrepit at a spa. His touch is least happy when, complying too facilely with the gathering cult of sensibility, he indulges in rote-learned displays of emotionalism and good-heartedness. His most sustainedly invigorating work can perhaps be found in *The Adventures of Roderick Random* (1748), *The Adventures of Peregrine Pickle* (1751), and (an altogether more interesting encounter with the dialects of sensibility) *The Expedition of Humphry Clinker* (1771).

Sterne. An experiment of a radical and seminal kind is Laurence Sterne's *Tristram Shandy* (1759–67), which, drawing on a tradition of learned wit from Erasmus and Rabelais to Burton and Swift, provides a brilliant comic critique of the progress of the English novel to date. The focus of attention is shifted from the fortunes of the hero himself to the nature of his family, environment, and heredity, and dealings within that family offer repeated images of human unrelatedness and disconnection. Tristram, the narrator, is isolated in his own privacy and doubts how much, if anything, he can know certainly even about himself. Sterne is explicit about the influence of Lockean psychology on his writing, and the book, fascinated with the fictive energies of the imagination, is filled with characters reinventing or mythologizing the conditions of their own lives. It also draws zestful stimulus from a concern with the limitations of language, both verbal and visual, and teases an intricate drama out of Tristram's imagining of, and playing to, the reader's likely responses. Sterne's *Sentimental Journey Through France and Italy* (1768) similarly defies conventional expectations of what a travel book might be. An apparently random collection of scattered experiences, it mingles affecting vignettes with episodes in a heartier, comic mode, but coherence of imagination is secured by the delicate insistence with which Sterne ponders how the impulses of sentimental and erotic feeling are psychologically interdependent.

Minor novelists. The work of these five giants was accompanied by interesting experiments from a number of lesser novelists. Sarah Fielding, for instance, Henry's sister, wrote penetratingly and gravely about friendship in *The Adventures of David Simple* (1744, with a sequel in 1753). Charlotte Lennox in *The Female Quixote* (1752) and Richard Graves in *The Spiritual Quixote* (1773) responded inventively to the influence of Cervantes, also discernible in the writing of Fielding, Smollett, and Sterne. John Cleland's *Memoirs of a Woman of Pleasure* (known as *Fanny Hill;* 1748–49) chose a more contentious path; in his charting of a young girl's sexual initiation, he experiments with minutely detailed ways of describing the physiology of intercourse. In emphatic contrast, Henry Mackenzie's *Man of Feeling* (1771) offers an extremist, and rarefied, version of the sentimental hero, while Horace Walpole's *Castle of Otranto* (1765) somewhat laboriously initiated the vogue for Gothic fiction. William Beckford's *Vathek* (1786), Ann Radcliffe's *Mysteries of Udolpho* (1794), and Matthew Lewis' *Monk* (1796) are among the more distinctive of its successors. But the most engaging and thoughtful minor novelist of the period is Fanny Burney, who was also an evocative and self-revelatory diarist and letter writer. Her *Evelina* (1778) and *Camilla* (1796) in particular handle with independence of invention and emotional insight the theme of a young woman negotiating her first encounters with a dangerous social world.

POETS AND POETRY AFTER POPE

Eighteenth-century poetry after Pope produced nothing that can compete with achievements on the scale of *Clarissa* and *Tristram Shandy;* but much that was vital was accomplished. William Collins' *Odes on Several Descriptive and Allegoric Subjects* (1747), for instance, displays great technical ingenuity and a resonant insistence on the imagination and the passions as poetry's true realm. The odes also mine vigorously the potentiality of personification as a medium for poetic expression. In his *Elegy Written in a Country Churchyard* (1751), Thomas Gray revisited the terrain of such recent poems as Thomas Parnell's *Night-Piece on Death* (1722) and Robert Blair's poem *The Grave* (1743) and discovered a tensely humane eloquence far beyond his predecessors' powers. In later odes, particularly *The Progress of Poesy* (1757), Gray successfully sought close imitation of the original Pindaric form, even emulating Greek rhythms in English, while developing ambitious ideas about cultural continuity and renewal. Gray's fascination with the potency of primitive art (as evidenced in another great ode, *The Bard,* 1757) is part of a larger movement of taste, of which the contemporary enthusiasm for James Macpherson's alleged translations of Ossian (1760–63) is a further indicator.

Experimentation in poetic expression

Another eclectically learned and energetically experimental poet is Christopher Smart, whose renown rests largely on two poems. *Jubilate Agno* (written during confinement in various asylums between 1758/59 and 1763 but not published until 1939) is composed in free verse and experiments with applying the antiphonal principles of Hebrew poetry to English. *A Song to David* (1763) is a rhapsodic hymn of praise, blending enormous linguistic vitality with elaborate structural patterning. Both contain encyclopaedic gatherings of recondite and occult lore, numerous passages of which modern scholarship has yet to explicate satisfactorily, but the poetry is continually energized by minute alterations of tone, startling conjunctions of material, and a unique alertness to the mystery of the commonplace. Smart was also a superb writer of hymns, a talent in which his major contemporary rival was William Cowper in his *Olney Hymns* (1779). Both are worthy successors to the richly inventive work of Isaac Watts in the first half of the century. Elsewhere, Cowper can write with buoyant humour and satiric relaxation, as when, for instance, he

wryly observes from the safety of rural seclusion the evils of town life. But some of his most characterful poetry emerges from a painfully intense experience of withdrawal and isolation. His rooted Calvinism caused him periods of acute despair when he could see no hope of admission to salvation, a mood chronicled with grim precision in his masterly short poem *The Castaway* (written 1799). His most extended achievement is *The Task* (1785), an extraordinary fusion of disparate interests, working calmly toward religious praise and pious acceptance.

Burns. The 1780s brought publishing success to Robert Burns for his *Poems, Chiefly in the Scottish Dialect* (1786). Drawing on the precedents of Allan Ramsay and Robert Fergusson, Burns demonstrated how Scottish idioms and ballad modes could lend a new vitality to the language of poetry. Although born a poor tenant farmer's son, Burns had made himself well versed in English literary traditions, and his innovations were fully premeditated. His range is wide, from uninhibitedly passionate love songs to sardonic satires on moral and religious hypocrisy, of which the monologue *Holy Willie's Prayer* (written 1785) is an outstanding example. His work bears the imprint of the revolutionary decades in which he wrote, and recurrent in much of it are a joyful hymning of freedom, both individual and national, and an instinctive belief in the possibility of a new social order.

Goldsmith. Two other major poets, both of whom also achieved distinction in an impressive array of nondramatic modes, demand attention: Oliver Goldsmith and Samuel Johnson. Goldsmith's contemporary fame as a poet rested chiefly on *The Traveller* (1764), *The Deserted Village* (1770), and the incomplete *Retaliation* (1774). The last, published 15 days after his own death, is a dazzling series of character portraits in the form of mock epitaphs on a group of his closest acquaintances. *The Traveller,* a philosophical comparison of the differing national cultures of western Europe and the degrees of happiness their citizens enjoy, is narrated by a restless wanderer whose heart yet yearns after his own native land, where his brother still dwells. In *The Deserted Village* the experience is one of enforced exile, as an idealized village community is ruthlessly broken up in the interests of landed power. A comparable story of a rural idyll destroyed (though, this time, narrative artifice allows its eventual restoration) is at the centre of his greatly popular but tonally elusive novel, *The Vicar of Wakefield* (1766). He was also a deft and energetic practitioner of the periodical essay, contributing to at least eight journals between 1759 and 1773. His *Citizen of the World,* originally published in *The Public Ledger* in 1760–61, uses the device of a Chinese traveler whose letters home comment tolerantly but shrewdly on his English experiences. He also produced two stage comedies, one of which, *She Stoops to Conquer* (1773), is one of the few incontrovertible masterpieces of the theatre after the death of Farquhar in 1707.

Johnson's poetry and prose. Goldsmith belonged to the circle of a writer of still ampler range and outstanding intellect, Samuel Johnson. Pope recognized Johnson's poetical promise in *London* (1738), an invigorating reworking of Juvenal's third satire as a castigation of the decadence of contemporary Britain. His finest poem, *The Vanity of Human Wishes* (1749), also takes its cue from Juvenal, this time his 10th satire. It is a tragic meditation on the pitiful spectacle of human unfulfillment, which yet ends with an urgent prayer of Christian hope. But, great poet though he was, the lion's share of his formidable energies was expended on prose. From his early years in London he lived by his pen and gave himself unstintingly to satisfy the booksellers' demands. Yet he managed to sustain a remarkable coherence of ethical ambition and personal presence throughout his voluminous labours. His twice-weekly essays for *The Rambler* (1750–52), for instance, consistently show his powers at their fullest stretch, handling an impressive array of literary and moral topics with a scrupulous intellectual gravity and attentiveness. Many of the preoccupations of *The Vanity of Human Wishes* and the *Rambler* essays reappear in *Rasselas* (1759), which catalogues with profound resource the vulnerability of human philosophies of life to humiliation at the hands of life itself. His forensic brilliance can be seen in his relentless review of Soame Jenyns' *Free Inquiry into the Nature and Origin of Evil* (1757), which caustically dissects the latter's complacent attitude to human suffering, and his analytic capacities are evidenced at their height in the successful completion of two major projects, his innovative *Dictionary of the English Language* (1755) and the great edition of Shakespeare's plays (1765). His last years produced much political writing (including the humanely resonant *Thoughts on the Late Transactions Respecting Falkland's Islands,* 1771); the socially and historically alert *Journey to the Western Islands of Scotland,* 1775; and the consummate *Lives of the Poets,* 1779–81. The latter was the climax of 40 years' writing of poetical biographies, including the multifaceted *Account of the Life of Mr. Richard Savage* (1744). These last lives, covering the period from Cowley to the generation of Gray, show Johnson's mastery of the biographer's art of selection and emphasis and (together with the preface and notes to his Shakespeare edition) contain the most provocative critical writing of the century. Although his allegiances lay with neoclassical assumptions about poetic form and language, his capacity for improvisatory responsiveness to practice that lay outside the prevailing decorums should not be underrated. His final faith, however, in his own creative practice as in his criticism, was that the greatest art eschews unnecessary particulars and aims toward carefully pondered and ambitious generalization. The same creed was eloquently expounded by another member of the Johnson circle, Sir Joshua Reynolds, in his 15 *Discourses* (delivered to the Royal Academy between 1769 and 1790, but first published collectively in 1797).

Johnson as essayist, editor, and political writer

The other prime source of Johnson's fame, his reputation as a conversationalist of epic genius, rests on the detailed testimony of contemporary memorialists including Fanny Burney, Hester Lynch Piozzi, and Sir John Hawkins. But the key text is James Boswell's magisterial *Life of Samuel Johnson* (1791). This combines in unique measure a deep respect for its subject's ethical probity and resourceful intellect with a far from inevitably complimentary eye for the telling details of his personal habits and deportment. Boswell manifests rich dramatic talent and a precise ear for conversational rhythms in his re-creation, and orchestration, of the debates that lie at the heart of this great biography. Another dimension of Boswell's literary talent came to light in the 1920s and '30s when two separate hoards of unpublished manuscripts were discovered. In these he is his own subject of study. The 18th century had not previously produced much autobiographical writing of the first rank, though the actor and playwright Colley Cibber's flamboyant *Apology for the Life of Mr. Colley Cibber* (1740) and William Cowper's sombre *Memoir* (written about 1766, first published in 1816) are two notable exceptions. But the drama of Boswell's self-observations has a richer texture than either of these. In the *London Journal* especially (covering 1762–63, first published in 1950), he records the processes of his dealings with others and of his own self-imaginings with a sometimes unnerving frankness and a tough willingness to ask difficult questions of himself.

Boswell's *Life of Samuel Johnson*

Boswell narrated his experiences at the same time as, or shortly after, they occurred. Edward Gibbon, on the other hand, taking full advantage of hindsight, left in manuscript at his death six autobiographical fragments, all having much ground in common, but each telling a subtly different version of his life. Though he was in many ways invincibly more reticent than Boswell, Gibbon's successive explorations of his own history yet form a movingly resolute effort to see the truth clearly. These writings were undertaken after the completion of the great work of his life, *The History of the Decline and Fall of the Roman Empire* (1776–88). He brought to the latter an untiring dedication in the gathering and assimilation of knowledge, an especial alertness to evidence of human fallibility and failure, and a powerful ordering intelligence supported by a delicate sense of aesthetic coherence. His central theme—that the destruction of the Roman Empire was the joint triumph of barbarism and Christianity—is sustained with formidable ironic resource. (M.Co.)

The Romantic period

THE NATURE OF ROMANTICISM

As a term to cover the most distinctive writers who flourished in the last years of the 18th century and the first decades of the 19th, "Romantic" is indispensable but also a little misleading: there was no self-styled "Romantic movement" at the time, and the great writers of the period did not call themselves Romantics.

Many of the age's foremost writers thought that something new was happening in the world's affairs, nevertheless. Blake's affirmation in 1793 that "A new Heaven is begun . . . " was matched a generation later by Shelley's "The world's great age begins anew." "These, these shall give the world/Another heart, and other pulses" wrote Keats, referring to Rousseau and Wordsworth. Fresh ideals came to the fore: in particular the ideal of freedom, long cherished in England, was being extended to every range of human endeavour. As that ideal swept through Europe, it became natural to believe that the age of tyrants might soon end.

Role of individual feeling and thought

The feature most likely to strike a reader turning to the poets of the time after reading their immediate predecessors is the new role of individual feeling and thought. Where the main trend of 18th-century poetics had been to praise the general, to see the poet as a spokesman of society, addressing a cultivated and homogeneous audience and having as his end the conveyance of "truth," the Romantics found the source of poetry in the particular, unique experience. Blake's marginal comment on Sir Joshua Reynolds' *Discourses* expresses the position with characteristic vehemence: "to generalise is to be an idiot; to particularise is the alone distinction of merit." The poet was seen as an individual distinguished from his fellows by the intensity of his perceptions, taking as his basic subject matter the workings of his own mind. The implied attitude to an audience varied accordingly: although Wordsworth maintained that a poet did not write "for Poets alone, but for Men," for Shelley the poet was "a nightingale who sits in darkness and sings to cheer its own solitude with sweet sounds," and Keats declared "I never wrote one single line of Poetry with the least Shadow of public thought." Poetry was regarded as conveying its own truth; sincerity was the criterion by which it was to be judged. Provided the feeling behind it was genuine, the resulting creation must be valuable.

The emphasis on feeling—seen perhaps at its finest in the poems of Burns—was in some ways a continuation of the earlier "cult of sensibility"; and it is worth remembering that Pope praised his father as having known no language but the language of the heart. But feeling had begun to receive particular emphasis and is found in most of the Romantic definitions of poetry. Wordsworth called it "the spontaneous overflow of powerful feeling," and in 1833 John Stuart Mill defined "natural poetry" as "Feeling itself, employing Thought only as the medium of its utterance." It followed that the best poetry was that in which the greatest intensity of feeling was expressed, and hence a new importance was attached to the lyric. The degree of intensity was affected by the extent to which the poet's imagination had been at work; as Coleridge saw it, the imagination was the supreme poetic quality, a quasi-divine creative force that made the poet a godlike being. Romantic theory thus differed from the neoclassic in the relative importance it allotted to the imagination: Samuel Johnson had seen the components of poetry as "invention, imagination and judgement" but William Blake wrote: "One Power alone makes a Poet: Imagination, the Divine Vision." The judgment, or conscious control, was felt to be secondary; the poets of this period accordingly placed great emphasis on the workings of the unconscious mind, on dreams and reveries, on the supernatural, and on the childlike or primitive view of the world, this last being regarded as valuable because its clarity and intensity had not been overlaid by the restrictions of civilized "reason." Rousseau's sentimental conception of the "noble savage" was often invoked, and often by those who were ignorant that the phrase is Dryden's or that the type was adumbrated in the "poor Indian" of Pope's *Essay on Man*. A further sign of the diminished stress placed on judgment is the Romantic attitude to form: if poetry must be spontaneous, sincere, intense, it should be fashioned primarily according to the dictates of the creative imagination. Wordsworth advised a young poet, "You feel strongly; trust to those feelings, and your poem will take its shape and proportions as a tree does from the vital principle that actuates it." This organic view of poetry is opposed to the classical theory of "genres," each with its own linguistic decorum; and it led to the feeling that poetic sublimity was unattainable except in short passages.

Importance of the imagination

Hand in hand with the new conception of poetry and the insistence on a new subject matter went a demand for new ways of writing. Wordsworth and his followers, particularly Keats, found the prevailing poetic diction of the later 18th century stale and stilted, or "gaudy and inane," and totally unsuited to the expression of their perceptions. It could not be, for them, the language of feeling, and Wordsworth accordingly sought to bring the language of poetry back to that of common speech. His theories of diction have been allowed to loom too large in critical discussion: his own best practice very often differs from his theory. Nevertheless, when Wordsworth published his preface to *Lyrical Ballads* in 1800, the time was ripe for a change: the flexible diction of earlier 18th-century poetry had hardened into a merely conventional language and, with the notable exceptions of Blake and Burns, little first-rate poetry had been produced (as distinct from published) in Britain since the 1740s.

POETRY

Blake, Wordsworth, and Coleridge. Useful as it is to trace the common elements in Romantic poetry, there was little conformity among the poets themselves. It is misleading to read the poetry of the first Romantics—William Blake, Samuel Taylor Coleridge, and William Wordsworth, for example—as if it had been written primarily to express their feelings. Their concern was rather to change the intellectual climate of the age. Blake had been dissatisfied since boyhood with the current state of poetry and the drabness of contemporary thought. His early development of a protective shield of mocking humour with which to face a world in which science had become trifling and art inconsequential is visible in the satirical *An Island in the Moon* (written *c.* 1784–85); he then took the bolder step of setting aside sophistication in the visionary *Songs of Innocence* (1789). His desire for renewal encouraged him to view the outbreak of the French Revolution as a momentous event. Tradition has it that he openly wore the revolutionary red cockade in the streets of London. In powerful works, such as *The Marriage of Heaven and Hell* (1790–93) and *Songs of Experience* (1794), he attacked the hypocrisies of the age and the impersonal cruelties resulting from the dominance of analytic reason in contemporary thought. As it became clear that the ideals of the Revolution were not likely to be realized in his time, he renewed his efforts to revise his contemporaries' view of the universe and to construct a new mythology centred not in the God of the Bible but in Urizen, a figure of reason and law who he believed to be the true deity worshiped by his contemporaries. The story of Urizen's rise to provide a fortification against the chaos created by loss of a true human spirit was set out first in "Prophetic Books" such as *The First Book of Urizen* (1794) and then, more ambitiously, in the unfinished manuscript *Vala*, or *The Four Zoas*, written from about 1796 to about 1807.

Dissatisfaction with the intellectual climate

Later Blake shifted his poetic aim once more. Instead of attempting a narrative epic on the model of *Paradise Lost* he produced the more loosely organized visionary narratives of *Milton* (1804–08) and *Jerusalem* (1804–20) where, still using mythological characters, he portrayed the imaginative artist as the hero of society and forgiveness as the greatest human virtue.

Wordsworth and Coleridge, meanwhile, were exploring the implications of the Revolution more intricately. Neither could easily forget the excitement of the period immediately following its outbreak. Wordsworth, who lived in France in 1791–92 and fathered an illegitimate child

there, was distressed when, soon after his return, Britain declared war on the republic, dividing his allegiance. While sharing the horror of his contemporaries at the massacres in Paris, he knew at first hand the idealism and generosity of spirit to be found among the revolutionaries. For the rest of his career he was to brood on the implications of those events, trying to develop a view of humanity that would be faithful to his twin sense of the pathos of individual human fates and of the unrealized potentialities in humanity as a whole. The first factor emerges in his early manuscript poems "The Ruined Cottage" and "The Pedlar" (both to form part of the later *Excursion*); the second was developed from 1797, when he and his sister, Dorothy, with whom he was living in the west of England, were in close contact with Coleridge. Stirred simultaneously by Dorothy's immediacy of feeling, manifested everywhere in her *Journals* (written 1798–1803, published 1897), and by Coleridge's imaginative and speculative genius, he produced the poems collected in *Lyrical Ballads* (1798). The volume began with Coleridge's "Rime of the Ancient Mariner," continued with poems displaying delight in the powers of nature and the humane instincts of ordinary people, and concluded with the meditative "Lines written a few miles above Tintern Abbey," an attempt to set out his mature faith in nature and humanity.

His investigation of the relationship between nature and the human mind continued in the long autobiographical poem addressed to Coleridge and later entitled *The Prelude* (1805; revised continuously and published posthumously, 1850). Here he traced the value for a poet of having been a child "fostered alike by beauty and by fear" (in true Gothic style) by an upbringing in sublime surroundings. The poem also makes much of the work of memory, a theme that reaches its most memorable expression in the "Ode: Intimations of Immortality from Recollections of Early Childhood." In poems such as "Michael" and "The Brothers," by contrast, written for the second volume of *Lyrical Ballads* (1800), Wordsworth dwelt on the pathos and potentialities of ordinary lives.

Coleridge's poetic development during these years paralleled Wordsworth's. Having briefly brought together images of nature and the mind in "The Eolian Harp" (1796), he had devoted himself to more public concerns in poems of political and social prophecy, such as "Religious Musings" and "The Destiny of Nations." Becoming disillusioned with contemporary politics, however, and encouraged by Wordsworth, he turned back to the relationship between nature and the human mind. Poems such as "This Lime-Tree Bower My Prison," "The Nightingale," and "Frost at Midnight" (now sometimes called the "conversation poems" but entitled more accurately by Coleridge himself "Meditative Poems in Blank Verse") combine sensitive descriptions of nature with subtlety of psychological comment. "Kubla Khan" (1797, published 1816), a poem that Coleridge said came to him in "a kind of Reverie," opened a new vein of exotic writing, which he exploited further in the supernaturalism of "The Ancient Mariner" and the unfinished "Christabel." After his visit to Germany in 1798–99, however, renewed attention to the links between the subtler forces in nature and the human psyche bore fruit in letters and notebooks; simultaneously, his poetic output became sporadic. "Dejection: An Ode" (1802), another meditative poem, which first took shape as a letter to Sara Hutchinson, Wordsworth's sister-in-law, memorably describes the suspension of his "shaping spirit of Imagination."

Nature and the human mind in Coleridge's poetry

The work of both poets was directed back to national affairs during these years by the rise of Napoleon. In 1802 Wordsworth dedicated a number of sonnets to the patriotic cause. The death in 1805 of his brother John, who was serving as a sea captain, was a grim reminder that while he had been living in retirement as a poet others had been willing to sacrifice themselves for the public good. From this time the theme of duty was to be prominent in his poetry. His political essay *Concerning the Relations of Great Britain, Spain and Portugal . . . as Affected by the Convention of Cintra* (1809) agreed with Coleridge's periodical *The Friend* (1809–10) in deploring the decline of principle among statesmen. When *The Excursion* appeared in 1814 (the time of Napoleon's first exile), Wordsworth announced the poem as the central section of a longer projected work, *The Recluse*. This work was to be "a philosophical Poem, containing views of Man, Nature, and Society," and Wordsworth hoped to complete it by adding "meditations in the Author's own Person." The plan was not fulfilled, however, and *The Excursion* was left to stand in its own right as a poem of consolation for those who had been disappointed by the failure of French revolutionary ideals.

Both Wordsworth and Coleridge benefited from the advent in 1811 of the Regency, which brought a renewed interest in the arts. Coleridge's lectures on Shakespeare and literature became fashionable, his plays were briefly produced, and he gained further celebrity from the publication in 1816 of a volume of poems called *Christabel, Kubla Khan, A Vision: The Pains of Sleep. Biographia Literaria* (1817), the account of his own development, combined philosophy and literary criticism in a new way; the account was lastingly influential for the insights it contained. Coleridge settled at Highgate in 1816, and he was sought there as "the most impressive talker of his age" (in the words of the essayist William Hazlitt). His later religious writings made a considerable impact on the Victorians.

Coleridge's *Biographia Literaria*

Other poets of the early Romantic period. Several of the lesser poets of this generation were more popular in their own time. The somewhat insipid *Fourteen Sonnets* (1789) of William Lisle Bowles were received with enthusiasm by Coleridge and Wordsworth. Thomas Campbell is now chiefly remembered for his patriotic lyrics such as "Ye Mariners of England" and "The Battle of Hohenlinden" (1807) and for the critical preface to his *Specimens of the British Poets* (1819); Samuel Rogers has survived for his brilliant table talk (published 1856, after his death, as *Recollections of the Table-Talk of Samuel Rogers*), rather than for his poetry. One of the most popular poets of the day was Thomas Moore, whose *Irish Melodies* began to appear in 1807. His highly coloured Oriental fantasy *Lalla Rookh* (1817) was also immensely popular.

Robert Southey was closely associated with Wordsworth and Coleridge and was looked upon as a prominent member, with them, of the "Lake School" of poetry. His grandiose epic poems, such as *Thalaba the Destroyer* (1801) and *The Curse of Kehama* (1810), were successful in their own time, but his fame is based on his prose work—the vigorous *Life of Nelson* (1813), the *History of the Peninsular War* (1823–32), and his classic formulation of the children's tale "The Three Bears."

George Crabbe wrote poetry of another kind: his sensibility, his values, much of his diction, and his heroic couplet verse form belong very firmly to the 18th century. He differs from the earlier Augustans, however, in his subject matter, concentrating on realistic, unsentimental accounts of the life of the poor and the middle classes. He shows considerable narrative gifts in his collections of verse tales (in which he anticipates many short-story techniques) and great powers of description. His main works, *The Village* (1783), *The Borough* (1810), *Tales in Verse* (1812), and *Tales of the Hall* (1819), gained him great popularity in the earlier 19th century; after a long period of neglect he is widely recognized once more as a major poet.

The later Romantics: Shelley, Keats, and Byron. The poets of the next generation shared their predecessors' passion for liberty (now set in a new perspective by the Napoleonic wars) and were in a position to learn from their experiments. Percy Bysshe Shelley in particular was deeply interested in politics, coming early under the spell of the anarchistic views of William Godwin, whose *Enquiry Concerning Political Justice* had appeared in 1793. Shelley's revolutionary ardour, coupled with a zeal for the liberation of mankind and a passion for poetry, caused him to claim in his critical essay *A Defence of Poetry* (1821, published 1840) that "the most unfailing herald, companion, and follower of the awakening of a great people to work a beneficial change in opinion or institution, is poetry," and that poets are "the unacknowledged legislators of the world." This fervour burns throughout the early *Queen Mab* (1813), the long *Laon and Cythna*

Shelley's political zeal and passion for poetry

(retitled *The Revolt of Islam*, 1818), and the lyrical drama *Prometheus Unbound* (1820). Shelley saw himself at once as poet and prophet, as the fine "Ode to the West Wind" (1819) makes clear. Despite his firm grasp of practical politics, however, it is a mistake to look for concreteness in his poetry, where his concern is with subtleties of perception and with the underlying forces of nature: his most characteristic image is of sky and weather, of lights and fires. His poetic stance invites the reader to respond with similar outgoing aspiration. It adheres to the Rousseauistic belief in an underlying spirit in individuals, one truer to human nature itself than the behaviour evinced and approved by society. In that sense his material is transcendental and cosmic and his expression thoroughly appropriate. Possessed of great technical brilliance, he is, at his best, a poet of excitement and power.

John Keats, by contrast, was a poet so richly sensuous that his early work, such as *Endymion* (1818)—"a trial of my Powers of Imagination" he called it—could produce an over-luxuriant, cloying effect. As the program set out in his early poem "Sleep and Poetry" shows, however, Keats was also determined to discipline himself: even before February 1820, when he first began to cough blood, he may have known that he had not long to live, and he devoted himself to the expression of his vision with feverish intensity. He experimented with many kinds of poem: "Isabella" (published 1820), an adaptation of a tale by Boccaccio, is a tour de force of craftsmanship in its attempt to reproduce a medieval atmosphere. His epic fragment *Hyperion* (begun in 1818 and abandoned, published 1820; later begun again and published as *The Fall of Hyperion*, 1856) has a new spareness of imagery, but Keats soon found the style too Miltonic and decided to give himself up to what he called "other sensations." Some of these "other sensations" are found in the poems of 1819, Keats's annus mirabilis: "The Eve of St. Agnes" and the great odes, "To a Nightingale," "On a Grecian Urn," and "To Autumn." These, with the *Hyperion* poems, represent the summit of Keats's achievement, showing what has been called "the disciplining of sensation into symbolic meaning," the complex themes being handled with a concrete richness of detail. Study of his poems is incomplete without a reading of his superb letters, which show the full range of the intelligence at work in his poetry.

Keats's achievement

George Gordon, Lord Byron, who differed from Shelley and Keats in themes and manner, was at one with them in reflecting their shift toward "Mediterranean" themes. Having thrown down the gauntlet in his early poem *English Bards and Scotch Reviewers* (1809), in which he directed particular scorn at poems and poets of sensibility and sympathy and declared his own allegiance to Milton, Dryden, and Pope, he developed a poetry of dash and flair, in many cases with a striking hero. His two longest poems, *Childe Harold's Pilgrimage* (1812–18) and *Don Juan* (1819–24), his masterpiece, provided alternative personae for himself, the one a bitter and melancholy exile among the historic sites of Europe, the other a picaresque adventurer enjoying a series of amorous adventures. The gloomy and misanthropic vein was further mined in dramatic poems such as *Manfred* (1817) and *Cain* (1821), which helped to secure his reputation in Europe, but he is now remembered best for witty, ironic, and less portentous writings, such as *Beppo* (1818), in which he first used the ottava rima form. The easy, nonchalant, biting style developed there became a formidable device in *Don Juan* and in his satire on Southey, *The Vision of Judgment* (1822).

Minor poets of the later period. Of the lesser poets of this generation the best is undoubtedly John Clare, a Northamptonshire man of humble background. His natural simplicity and lucidity of diction, his intent observation, his almost classical poise, and the unassuming dignity of his attitude to life make him one of the most quietly moving of English poets. Thomas Lovell Beddoes, whose violent imagery and obsession with death and the macabre recall the Jacobean dramatists, represents an imagination at the opposite pole; considerable metrical virtuosity is displayed in the songs and lyrical passages from his oversensational tragedy *Death's Jest-Book* (begun 1825; published posthumously, 1850). Another minor writer who found inspiration in the 17th century was George Darley, some of whose songs from *Nepenthe* (1835) keep their place in anthologies. The comic writer Thomas Hood once enjoyed a great vogue but is now little read, although such poems of social protest as *The Song of the Shirt* (1843) and "The Bridge of Sighs," and the graceful *Plea of the Midsummer Fairies* (1827), are by no means negligible.

THE NOVEL: AUSTEN, SCOTT, AND OTHERS

At the turn of the century the Gothic mode, with its alternations between evocation of terror and appeal to sensibility, reached a peak of popularity with novels such as Ann Radcliffe's *Mysteries of Udolpho* (1794) and *The Italian* (1797) and Matthew Gregory Lewis' sensational *The Monk* (1796). These writers dealt with the supernatural and with human psychology far less adequately than did the poets, however, and appear to modern readers all the more shallow when compared with the great novelist Jane Austen. Her *Northanger Abbey* (begun in 1797; published posthumously, 1817) satirizes the Gothic novel, among other things, with complex irony; *Sense and Sensibility* (begun 1797; published 1811) mocks the contemporary cult of sensibility, while also displaying sympathetic understanding of the genuine sensitivities to which it appealed; *Pride and Prejudice* (begun 1796; published 1813) shows how sanity and intelligence can break through the opacities of social custom. The limitation suggested by her narrow range of settings and characters is illusory; working within these chosen limits, she observed and described very closely the subtleties of personal relationships, while also appealing to a sense of principle which, like Wordsworth and Coleridge, she believed to be threatened in a fragmenting and increasingly cosmopolitan society. These qualities come to full fruition in *Mansfield Park* (1814), *Emma* (1815), and *Persuasion* (1817). A master of dialogue, she wrote with economy, hardly wasting a word.

The underlying debate concerning the nature of society is reflected also in the novels of Sir Walter Scott. After his earlier success as a poet in such narrative historical romances as *The Lay of the Last Minstrel* (1805), *Marmion* (1808), and *The Lady of the Lake* (1810), he turned to prose and wrote more than 20 novels, several of which concerned heroes who were growing up, as he and his contemporaries had done, in a time of revolutionary turmoil. In the best, such as *Waverley* (1814), *Old Mortality* (1816), and *The Heart of Midlothian* (1818), he reconstructs the recent past of his country, Scotland, from still surviving elements. His stress on the values of gallantry, fortitude, and human kindness, along with his picture of an older society in which all human beings have a recognized standing and dignity, appealed to an England in which class divisions were exacerbated by the new industrialism. His historical romances were to inspire many followers in the emerging new nations of Europe. Thomas Love Peacock's seven novels, by contrast, are conversation pieces in which many of the pretensions of the day are laid bare in the course of witty, animated, and genial talk. *Nightmare Abbey* (1818) explores the extravagances of contemporary intellectualism and poetry; the more serious side of his satire is shown in such passages as Mr. Cranium's lecture on phrenology in *Headlong Hall* (1816). The Gothic mode was developed interestingly by Mary Wollstonecraft Shelley (the daughter of William Godwin), whose *Frankenstein; or, The Modern Prometheus* (1818) explores the horrific possibilities of new scientific discoveries, and Charles Robert Maturin, whose *Melmoth the Wanderer* (1820) has, with all its absurdity, a striking intensity. Among lesser novelists may be mentioned Maria Edgeworth, whose realistic didactic novels of the Irish scene inspired Scott; Susan Edmonstone Ferrier, a Scot with her own vein of racy humour; John Galt, whose *Annals of the Parish* (1821) is a minor classic; and James Hogg, remembered for his remarkable *Private Memoirs and Confessions of a Justified Sinner* (1824), a powerful story of Calvinism and the supernatural.

The nature of society in Scott's works

MISCELLANEOUS PROSE

The Romantic emphasis on individualism is reflected in much of the prose of the period, particularly in criti-

Hazlitt, Lamb, and De Quincey

cism and the familiar essay. Among the most vigorous, forthright, and least mannered writing is that of William Hazlitt, an energetic, enthusiastic, and subjective critic whose most characteristic work is seen in his collections of lectures *On the English Poets* (1818) and *On the English Comic Writers* (1819) and in *The Spirit of the Age* (1825), a series of valuable portraits of his contemporaries. In *The Essays of Elia* (1823) and *The Last Essays of Elia* (1833) Charles Lamb, an even more personal essayist, projects, with apparent artlessness, a carefully managed portrait of himself—charming, whimsical, witty, sentimental, warm-hearted, nostalgic, and sociable; as his fine *Letters* show, however, he could on occasion produce mordant satire. Thomas De Quincey also appealed to the new interest in personal writing, producing a colourful account of his early experiences in *Confessions of an English Opium Eater* (1821, revised and enlarged in 1856). His unusual gift of evoking states of dream and nightmare is best seen in essays such as "The English Mail Coach" and "On the Knocking at the Gate in *Macbeth*" and in his various autobiographical pieces.

Of writers who might be called surviving classicists, the most notable is Walter Savage Landor, whose detached, lapidary style is seen at its best in some brief lyrics and in a series of erudite *Imaginary Conversations,* which began to appear in 1824. The anti-Romantic point of view received its most pungent expression in the pages of the journals: the Whig quarterly *Edinburgh Review* (begun 1802), edited by Francis Jeffrey, was followed by its Tory rivals *The Quarterly Review* (begun 1809) and the monthly *Blackwood's Magazine* (begun 1817). Their criticism was by no means always unjust and summed up much contemporary opinion; but the reviewers were too willing to judge the new poetry by their own settled standards, missing what was genuinely innovative. In their attacks on many kinds of prejudice and abuse, on the other hand, they set a notable standard of fearless and independent journalism. Similar independence was shown by Leigh Hunt, whose outspoken journalism, particularly in his *Examiner* (begun 1808), was of considerable influence, and by William Cobbett, whose *Rural Rides* (collected in 1830 from his *Political Register*) gives a telling picture, in forceful and clear prose, of the English countryside of his day.

DRAMA

Despite the unusually strong interest in the theatre, little drama of note emerged at this time. Most major poets produced plays, but although Coleridge's *Osorio* and *Zapolya* were produced in 1813 and 1818, respectively, and Byron's *Marino Falieri* in 1821, the achievements were literary rather than dramatic. At the Theatre Royal in Drury Lane where the acting of John Philip Kemble and his sister, Sarah Siddons, had been much admired, the centre of attention from 1814 onward was Edmund Kean, whose impassioned performances captivated Keats, Hazlitt, and Byron and of whom Coleridge said "To see him act is like reading Shakespeare by flashes of lightning." Coleridge's lectures and notes, which, along with the essays of Lamb and Hazlitt, brought a psychological and historical approach to Shakespeare and other early dramatists, set new standards of dramatic criticism during the period.

(R.P.C.M./J.B.B.)

The Post-Romantic and Victorian eras

Introspection in the literature of the age

Self-consciousness was the quality that John Stuart Mill identified, in 1838, as "the daemon of the men of genius of our time." Introspection was inevitable in the literature of an immediately Post-Romantic period, and the age itself was as prone to self-analysis as were its individual authors. William Hazlitt's essays *The Spirit of the Age* (1825) were echoed by Mill's articles of the same title in 1831, by Thomas Carlyle's essays "Signs of the Times" (1829) and "Characteristics" (1831), and by Richard Henry Horne's *New Spirit of the Age* in 1844.

This persistent scrutiny was the product of an acute sense of change. Britain had emerged from the long war with France (1793–1815) as a great power and as the world's predominant economy. Visiting England in 1847, the American writer Ralph Waldo Emerson observed of the English that "The modern world is theirs. They have made and make it day by day."

This new status as the world's first urban and industrialized society was responsible for the extraordinary wealth, vitality, and self-confidence of the period. Abroad these energies expressed themselves in the growth of the British Empire. At home they were accompanied by rapid social change and fierce intellectual controversy.

The juxtaposition of this new industrial wealth with a new kind of urban poverty is only one of the paradoxes that characterize this long and diverse period. In religion the climax of the Evangelical revival coincided with an unprecedentedly severe set of challenges to faith. In politics a widespread commitment to economic and personal freedom was, nonetheless, accompanied by a steady growth in the power of the state. The prudery for which the Victorian Age is notorious in fact went hand in hand with an equally violent immoralism, seen, for example, in Algernon Charles Swinburne's poetry or the writings of the Decadents. Most fundamentally of all, the rapid change that many writers interpreted as progress inspired in others a fierce nostalgia. Enthusiastic rediscoveries of ancient Greece, Elizabethan England, and, especially, the Middle Ages by writers, artists, architects, and designers made this age of change simultaneously an age of active and determined historicism.

John Stuart Mill caught this contradictory quality, with characteristic acuteness, in his essays on Jeremy Bentham (1838) and Samuel Taylor Coleridge (1840). Every contemporary thinker, he argued, was indebted to these two "seminal minds." Yet Bentham, as the enduring voice of the Enlightenment, and Coleridge, as the chief English example of the Romantic reaction against it, held diametrically opposed views.

A similar sense of sharp controversy is given by Carlyle in *Sartor Resartus* (1833–34). An eccentric philosophical fiction in the tradition of Swift and Sterne, the book argues for a new mode of spirituality in an age that Carlyle himself suggests to be one of mechanism. Carlyle's choice of the novel form and the book's humour, generic flexibility, and political engagement point forward to distinctive characteristics of Victorian literature.

EARLY VICTORIAN LITERATURE: THE AGE OF THE NOVEL

Several major figures of English Romanticism lived on into this period. Coleridge died in 1834, De Quincey in 1859. Wordsworth succeeded Southey as poet laureate in 1843 and held the post until his own death seven years later. Posthumous publication caused some striking chronological anomalies. Shelley's "Defence of Poetry" was not published until 1840. Keats's letters appeared in 1848 and Wordsworth's *Prelude* in 1850.

Despite this persistence critics of the 1830s felt that there had been a break in the English literary tradition, which they identified with the death of Byron in 1824. The deaths of Jane Austen in 1817 and Sir Walter Scott in 1832 should perhaps have been seen as even more significant, for the new literary era has, with justification, been seen as the age of the novel.

Dickens. Charles Dickens first attracted attention with the descriptive essays and tales originally written for newspapers, beginning in 1833, and collected as *Sketches by "Boz"* (1836). On the strength of this volume Dickens contracted to write a historical novel in the tradition of Scott (eventually published as *Barnaby Rudge* in 1841). By chance his gifts were turned into a more distinctive channel. In February 1836 he agreed to write the text for a series of comic engravings. The unexpected result was *The Pickwick Papers* (1836–37), one of the funniest novels in English literature. By July 1837 sales of the monthly installments exceeded 40,000 copies. Dickens' extraordinary popular appeal and the enormous imaginative potential of the Victorian novel were simultaneously established.

Serial publication of Dickens' work

The chief technical features of Dickens' fiction were also formed by this success. Serial publication encouraged the use of multiple plot and required that each episode be individually shaped. At the same time it produced an unprecedentedly close relationship between author and

reader. Part dramatist, part journalist, part mythmaker, and part wit, Dickens took the picaresque tradition of Smollett and Fielding and gave it a Shakespearean vigour and variety.

His early novels have been attacked at times for sentimentality, melodrama, or shapelessness. They are now increasingly appreciated for their comic or macabre zest and their poetic fertility. *Dombey and Son* (1846–48) marks the beginning of Dickens' later period. He thenceforth combined his gift for vivid caricature with a stronger sense of personality, designed his plots more carefully, and used symbolism to give his books greater thematic coherence. Of the masterpieces of the next decade, *David Copperfield* (1849–50) uses the form of a fictional autobiography to explore the great Romantic theme of the growth and comprehension of the self. *Bleak House* (1852–53) addresses itself to law and litigiousness, *Hard Times* (1854) is a Carlylian defense of art in an age of mechanism, and *Little Dorrit* (1855–57) dramatizes the idea of imprisonment, both literal and spiritual. Two great novels, both involved with issues of social class and human worth, appeared in the 1860s: *Great Expectations* (1860–61) and *Our Mutual Friend* (1864–65). His final book, *The Mystery of Edwin Drood* (published posthumously, 1870), was left tantalizingly uncompleted at the time of his death.

Thackeray, Gaskell, and others. Unlike Dickens, William Makepeace Thackeray came from a wealthy and educated background. The loss of his fortune at age 22, however, meant that he too learned his trade in the field of sketch writing and occasional journalism. His early fictions were published as serials in *Fraser's Magazine* or as contributions to the great Victorian comic magazine *Punch* (founded 1841). For his masterpiece, *Vanity Fair* (1847–48), however, he adopted Dickens' procedure of publication in monthly parts. Thackeray's satirical acerbity is here combined with a broad narrative sweep, a sophisticated self-consciousness about the conventions of fiction, and an ambitious historical survey of the transformation of English life in the years between the Regency and the mid-Victorian period. His later novels never match this sharpness. *Vanity Fair* was subtitled "A Novel Without a Hero." Subsequently, it has been suggested, a more sentimental Thackeray wrote novels without villains.

Elizabeth Gaskell began her career as one of the "Condition of England" novelists of the 1840s, responding like Frances Trollope, Benjamin Disraeli, and Charles Kingsley to the economic crisis of that troubled decade. *Mary Barton* (1848) and *Ruth* (1853) are both novels about social problems, as is *North and South* (1854–55), although, like her later work, this book also has a psychological complexity that anticipates George Eliot's novels of provincial life.

Variety of subgenres

Political novels, religious novels, historical novels, sporting novels, Irish novels, crime novels, and comic novels all flourished in this period. The years 1847–48, indeed, represent a pinnacle of simultaneous achievement in English fiction. In addition to *Vanity Fair, Dombey and Son,* and *Mary Barton,* they saw the completion of Disraeli's trilogy of political novels—*Coningsby* (1844), *Sybil* (1845), and *Tancred* (1847)—and the publication of first novels by Anne, Charlotte, and Emily Brontë; Charles Kingsley; and Anthony Trollope. For the first time literary genius appeared to be finding its most natural expression in prose fiction, rather than in poetry or drama. By 1853 the poet Arthur Hugh Clough would concede that "the modern novel is preferred to the modern poem."

The Brontës. In many ways, however, the qualities of Romantic verse could be absorbed, rather than simply superseded, by the Victorian novel. This is suggested clearly by the work of the Brontë sisters. Growing up in a remote but cultivated vicarage in Yorkshire, they invented, as children, the imaginary kingdoms of Angria and Gondal. These inventions supplied the context for many of the poems in their first, and pseudonymous, publication, *Poems by Currer, Ellis and Acton Bell* (1846). Their Gothic plots and Byronic passions also informed the novels that began to be published in the following year.

Charlotte Brontë, like her sisters, appears at first sight to have been writing a literal fiction of provincial life. In her first novel, *Jane Eyre* (1847), for example, the heroine's choice between sexual need and ethical duty belongs very firmly to the mode of moral realism. But her hair's-breadth escape from a bigamous marriage with her employer, and the death by fire of his mad first wife derive from the rather different tradition of the Gothic novel. In *Shirley* (1849) Charlotte Brontë strove to be, in her own words, "as unromantic as Monday morning." In *Villette* (1853) the distinctive Gothic elements return to lend this study of the limits of stoicism an unexpected psychological intensity and drama.

Emily Brontë united these diverse traditions still more successfully in her only novel, *Wuthering Heights* (1847). Closely observed regional detail, precisely handled plot, and a sophisticated use of multiple internal narrators are combined with vivid imagery and an extravagantly Gothic theme. The result is a perfectly achieved study of elemental passions and the strongest possible refutation of the assumption that the age of the novel must also be an age of realism.

EARLY VICTORIAN VERSE

Tennyson. Despite the growing prestige and proliferation of fiction (some 40,000 titles are said to have been published in this period), this age of the novel was in fact also an age of great poetry. Alfred Tennyson made his mark very early with *Poems, Chiefly Lyrical* (1830) and *Poems* (1832; dated 1833), publications that led some critics to hail him as the natural successor to Keats and Shelley. A decade later, in *Poems* (1842), Tennyson combined in two volumes the best of his early work with a second volume of more recent writing. The collection established him as the outstanding poet of the era.

Tennyson's *Poems*

In his early work Tennyson brought an exquisite lyric gift to late-Romantic subject matter. The result is a poetry that, for all its debt to Keats, anticipates the French Symbolists of the 1880s. The death of his friend and supporter Arthur Hallam in 1833, however, left him vulnerable to accusations from less sympathetic critics that this highly subjective verse was insufficiently engaged with the public issues of the day. The second volume of the *Poems* of 1842 contains two remarkable responses to this challenge. One is the dramatic monologue, a technique developed independently by both Tennyson and Browning in the 1830s and the greatest formal innovation in Victorian poetry. The other is the form that Tennyson called the English Idyl, in which he combined brilliant vignettes of contemporary landscape with relaxed debate.

In the major poems of his middle period Tennyson combined the larger scale required by his new ambitions with his original gift for the brief lyric by building long poems out of short ones. *In Memoriam* (1850) is an elegy for Arthur Hallam, formed by 133 individual lyrics. Eloquent, vivid, and ample, it is at the same time an acute pathological study of individual grief and the central Victorian statement of the problems posed by the decline of Christian faith. *Maud* (1855) assembles 27 lyric poems into a single dramatic monologue that disturbingly explores the psychology of violence.

Tennyson became poet laureate in 1850 and wrote some apt and memorable poems on patriotic themes. The chief work of his later period, however, was *Idylls of the King* (1859, revised 1885). An Arthurian epic, it offers a sombre vision of an idealistic community in decay. Some passages are brilliant, but even Tennyson's contemporaries found it on the whole oddly inhibited and lacking in intellectual substance.

G.K. Chesterton described Tennyson as "a suburban Virgil." The elegant Virgilian note was the last thing aimed at by his great contemporary Robert Browning. Browning's work was Germanic rather than Italianate, grotesque rather than idyllic, and colloquial rather than refined. The differences between Browning and Tennyson underline the creative diversity of the period.

Robert Browning and Elizabeth Barrett Browning. Deeply influenced by Shelley, Browning made two false starts. One was as a playwright, an ambition in which he persisted until 1846 and of which the one memorable product is *Pippa Passes* (1841). The other was as the late-Romantic poet of the confessional meditation *Pauline* (1833), the

closet drama *Paracelsus* (1835), and the difficult though innovatory narrative poem *Sordello* (1840).

Browning's *Dramatic Lyrics*

Browning found his individual and distinctively modern voice in 1842, with the volume *Dramatic Lyrics.* As the title suggests, it was a collection of dramatic monologues, among them "Porphyria's Lover," "Johannes Agricola in Meditation," and "My Last Duchess." The monologues make clear the radical originality of Browning's new manner: they involve the reader in sympathetic identification with the interior processes of criminal or unconventional minds, requiring active rather than merely passive engagement in the processes of moral judgment and self-discovery. More such monologues and some equally striking lyrics make up *Men and Women* (1855).

In 1846 Browning married Elizabeth Barrett. Though now remembered chiefly for her love poems *Sonnets from the Portuguese* (1850) and her experiment with the verse novel *Aurora Leigh* (1856; dated 1857), she was in her own lifetime far better known than her husband. Only with the publication of *Dramatis Personae* (1864) did Browning achieve the sort of fame that Tennyson had enjoyed for more than 20 years. The volume contains, in "Rabbi Ben Ezra," the most extreme statement of Browning's celebrated optimism. Hand in hand with this reassuring creed, however, go the skeptical intelligence and the sense of the grotesque displayed in such poems as "Caliban upon Setebos" and "Mr. Sludge, 'The Medium.' "

The Ring and the Book (1868–69) gives the dramatic monologue format unprecedented scope. Published in parts, like a Dickens novel, it tells a sordid murder story in a way that both explores moral issues and suggests the problematic nature of human knowledge. Browning's work after this date, though voluminous, is uneven.

Arnold and Clough. Matthew Arnold's first volume of verse, *The Strayed Reveller, and Other Poems* (1849), combined lyric grace with an acute sense of the dark philosophical landscape of the period. The title poem of his next collection, *Empedocles on Etna* (1852), is a sustained statement of the modern dilemma and a remarkable poetic embodiment of the process that Arnold called "the dialogue of the mind with itself." Arnold later suppressed this poem and attempted to write in a more impersonal manner. His greatest work ("Switzerland," "Dover Beach," "The Scholar-Gipsy") is, however, always elegiac in tone. In the 1860s he turned from verse to prose and became, with *Essays in Criticism* (1865), *Culture and Anarchy* (1869), and *Literature and Dogma* (1873), a lively and acute writer of literary, social, and religious criticism.

Arnold's friend Arthur Hugh Clough died young but managed, nonetheless, to produce three highly original poems. *The Bothie of Tober-na-Vuolich* (1848) is a narrative poem of modern life, written in hexameters. *Amours de Voyage* (1858) goes beyond this to the full-scale verse novel, using multiple internal narrators and vivid contemporary detail. *Dipsychus* (published posthumously in 1865 but not available in an unexpurgated version until 1951) is a remarkable closet drama that debates issues of belief and morality with a frankness, and a metrical liveliness, unequaled in Victorian verse.

EARLY VICTORIAN NONFICTIONAL PROSE

Carlyle's *French Revolution*

Carlyle may be said to have initiated Victorian literature with *Sartor Resartus.* He continued thereafter to have a powerful effect on its development. *The French Revolution* (1837), the book that made him famous, spoke very directly to this consciously postrevolutionary age. *On Heroes, Hero-Worship, and the Heroic in History* (1841) combined the Romantic idea of the genius with a further statement of the German transcendentalist philosophy, which Carlyle opposed to the influential doctrines of empiricism and utilitarianism. Carlyle's political writing, in *Chartism* (1839; dated 1840), *Past and Present* (1843), and the splenetic *Latter-day Pamphlets* (1850), inspired other writers to similar "prophetic" denunciations of laissez-faire economics and utilitarian ethics. The first importance of John Ruskin is as an art critic who, in *Modern Painters,* five volumes (1843–60), brought Romantic theory to the study of painting and forged an appropriate prose for its expression. But in *The Stones of Venice,* three volumes (1851–53), Ruskin took the political medievalism of Carlyle's *Past and Present* and gave it a poetic fullness and force. This imaginative engagement with social and economic problems continued into *Unto This Last* (1860), *The Crown of Wild Olive* (1866), and *Fors Clavigera* (1871–84). John Henry Newman was a poet, novelist, and theologian who wrote many of the tracts, published as *Tracts for the Times* (1833–41), that promoted the Oxford Movement in the Church of England. His subsequent religious development is memorably described in his *Apologia pro Vita Sua* (1864), one of the many great autobiographies of this introspective century.

LATE VICTORIAN LITERATURE

"The modern spirit," Matthew Arnold observed in 1865, "is now awake." In 1859 Charles Darwin had published *On the Origin of Species by Means of Natural Selection.* Historians, philosophers, and scientists were all beginning to apply the idea of evolution to new areas of study of the human experience. Traditional conceptions of man's nature and place in the world were, as a consequence, under threat. Walter Pater summed up the process, in 1866, by stating that "Modern thought is distinguished from ancient by its cultivation of the 'relative' spirit in place of the 'absolute.' "

The economic crisis of the 1840s was long past. But the fierce political debates that led first to the Second Reform Act of 1867 and then to the battles for the enfranchisement of women were accompanied by a deepening crisis of belief.

The novel. Late Victorian fiction may express doubts and uncertainties, but in aesthetic terms it displays a new sophistication and self-confidence. The American novelist Henry James wrote in 1884 that until recently the English novel had "had no air of having a theory, a conviction, a consciousness of itself behind it." Its acquisition of these things was due in no small part to Mary Ann Evans, better known as George Eliot. Initially a critic and translator, she was influenced, after the loss of her Christian faith, by the ideas of Ludwig Feuerbach and Auguste Comte. Her advanced intellectual interests combined with her sophisticated sense of the novel form to shape her remarkable fiction. Her early novels, *Adam Bede* (1859), *The Mill on the Floss* (1860), and *Silas Marner* (1861), are closely observed studies of English rural life that offer, at the same time, complex contemporary ideas and a subtle tracing of moral issues. Her masterpiece, *Middlemarch* (1871–72), is an unprecedentedly full study of the life of a provincial town, focused on the thwarted idealism of her two principal characters. George Eliot is a realist, but her realism involves a scientific analysis of the interior processes of social and personal existence.

George Eliot

Her fellow realist Anthony Trollope published his first novel in 1847 but only established his distinctive manner with *The Warden* (1855), the first of a series of six novels set in the fictional county of Barsetshire and completed in 1867. This sequence was followed by a further series, the six-volume Palliser group (1864–80), set in the world of British parliamentary politics. Trollope published an astonishing total of 47 novels, and his *Autobiography* (1883) is a uniquely candid account of the working life of a Victorian writer.

Trollope's series of novels

The third major novelist of the 1870s was George Meredith, who also worked as poet, journalist, and publisher's reader. His prose style is eccentric and his achievement uneven. His greatest work of fiction, *The Egoist* (1879), however, is an incisive comic novel that embodies the distinctive theory of the corrective and therapeutic powers of laughter expressed in his lecture "The Idea of Comedy" (1877).

This flowering of realist fiction was accompanied, perhaps inevitably, by a revival of its opposite, the romance. The 1860s produced a new subgenre, the sensation novel, seen at its best in the work of Wilkie Collins. Gothic novels and romances by Sheridan Le Fanu, Robert Louis Stevenson, William Morris, and Oscar Wilde; utopian fiction by Morris and Samuel Butler; and the early science fiction of H.G. Wells make it possible to speak of a full-scale romance revival.

Realism continued, however, to flourish, sometimes encouraged by the example of European Realist and Naturalist novelists. Both George Moore and George Gissing were influenced by Émile Zola, though both also reacted against him. The greatest novelist of this generation, however, was Thomas Hardy. His first published novel, *Desperate Remedies*, appeared in 1871 and was followed by 13 more before he abandoned prose to publish (in the 20th century) only poetry. His major fiction consists of the tragic novels of rural life, *The Mayor of Casterbridge* (1886), *Tess of the D'Urbervilles* (1891), and *Jude the Obscure* (1895). In these novels his brilliant evocation of the landscape and people of his fictional Wessex is combined with a sophisticated sense of "the ache of modernism."

Hardy's major fiction

Verse. The Pre-Raphaelite Brotherhood, formed in 1848 and unofficially reinforced a decade later, was founded as a group of painters but also functioned as a school of writers who linked the incipient Aestheticism of Keats and De Quincey to the Decadent movement of the fin de siècle. Dante Gabriel Rossetti collected his early writing in *Poems* (1870), a volume that led the critic Robert Buchanan to attack him as the leader of "The Fleshly School of Poetry." Rossetti combined some subtle treatments of contemporary life with a new kind of medievalism, seen also in *The Defence of Guenevere* (1858) by William Morris. The earnest political use of the Middle Ages found in Carlyle and Ruskin did not die out—Morris himself continued it and linked it, in the 1880s, with Marxism. But these writers also used medieval settings as a context that made possible an uninhibited treatment of sex and violence. The shocking subject matter and vivid imagery of Morris' first volume were further developed by Algernon Charles Swinburne, who, in *Atalanta in Calydon* (1865) and *Poems and Ballads* (1866), combined them with an intoxicating metrical power.

The carefully wrought religious poetry of Christina Rossetti is perhaps truer to the original, pious purposes of the Pre-Raphaelite Brotherhood. More interesting as a religious poet of this period, however, is Gerard Manley Hopkins, a Jesuit priest whose work was first collected as *Poems* in 1918, nearly 30 years after his death. Overpraised by modernist critics, who saw him as the sole great poet of the era, he was in fact an important minor talent and an ingenious technical innovator.

Hopkins' *Poems*

The 1890s witnessed a flowering of lyric verse, influenced intellectually by the critic and novelist Walter Pater and formally by contemporary French practice. Such writing was widely attacked as "decadent" for its improper subject matter and its consciously amoral doctrine of "art for art's sake." This stress upon artifice and the freedom of art from conventional moral constraints went hand in hand, however, with an exquisite craftsmanship and a devotion to intense emotional and sensory effects. Outstanding among the numerous poets publishing in the final decade of the century were John Davidson, Arthur Symons, Francis Thompson, Ernest Dowson, Lionel Johnson, and A.E. Housman. In *The Symbolist Movement in Literature* (1899) Symons suggested the links between this writing and European Symbolism and Impressionism. Thompson provides a vivid example of the way in which a decadent manner could, paradoxically, be combined with fierce religious enthusiasm. A rather different note was struck by Rudyard Kipling, who combined polemical force and sharp observation (particularly of colonial experience) with a remarkable metrical vigour.

THE VICTORIAN THEATRE

Early Victorian drama was a popular art form, appealing to an uneducated audience that demanded emotional excitement rather than intellectual subtlety. Vivacious melodramas did not, however, hold exclusive possession of the stage. The mid-century saw lively comedies by Dion Boucicault and Tom Taylor. In the 1860s T.W. Robertson pioneered a new realist drama, an achievement later celebrated by Arthur Wing Pinero in his charming sentimental comedy *Trelawny of the "Wells"* (1898). The 1890s were, however, the outstanding decade of dramatic innovation. Oscar Wilde crowned his brief career as a playwright with one of the few great high comedies in English, *The Importance of Being Earnest* (1895). At the same time the influence of Henrik Ibsen was helping to produce a new genre of serious "problem plays," such as Pinero's *Second Mrs. Tanqueray* (1893). J.T. Grein founded the Independent Theatre in 1891 to foster such work and staged there the first plays of George Bernard Shaw and translations of Ibsen.

VICTORIAN LITERARY COMEDY

Victorian literature began with such humorous books as *Sartor Resartus* and *The Pickwick Papers*. Despite the crisis of faith, the "Condition of England" question, and the ache of modernism, this note was sustained throughout the century. The comic novels of Dickens and Thackeray; the squibs, sketches, and light verse of Thomas Hood and Douglas Jerrold; the nonsense of Edward Lear and Lewis Carroll; and the humorous light fiction of Jerome K. Jerome and George Grossmith and his brother Weedon Grossmith are proof that this age, so often remembered for its gloomy rectitude, may in fact have been the greatest era of comic writing in English literature. (N.Sh.)

"Modern" English literature: the 20th century

FROM 1900 TO 1945

The Edwardians. The 20th century opened with great hope but also with some apprehension, for the new century marked the onset of a new millennium. For many, mankind was entering upon an unprecedented era. H.G. Wells's utopian studies, the aptly titled *Anticipations of the Reaction of Mechanical and Scientific Progress upon Human Life and Thought* (1901) and *A Modern Utopia* (1905), both captured and qualified this optimistic mood and gave expression to a common conviction that science and technology would transform the world in the century ahead. To achieve such transformation, outmoded institutions and ideals had to be replaced by ones more suited to the growth and liberation of the human spirit. The death of Queen Victoria in 1901 and the accession of Edward VII seemed to confirm that a franker, less inhibited era had begun.

Many writers of the Edwardian period, drawing widely upon the realistic and naturalistic conventions of the 19th century (upon Ibsen in drama and Balzac, Turgenev, Flaubert, Zola, Eliot, and Dickens in fiction) and in tune with the anti-Aestheticism unleashed by the trial of the archetypal Aesthete, Oscar Wilde, saw their task in the new century to be an unashamedly didactic one. In a series of wittily iconoclastic plays, of which *Man and Superman* (performed 1905, published 1903) and *Major Barbara* (performed 1905, published 1907) are the most substantial, George Bernard Shaw turned the Edwardian theatre into an arena for debate upon the principal concerns of the day: the question of political organization, the morality of armaments and war, the function of class and of the professions, the validity of the family and of marriage, and the issue of female emancipation. Nor was he alone in this, even if he was alone in the brilliance of his comedy. John Galsworthy made use of the theatre in *Strife* (1909) to explore the conflict between capital and labour, and in *Justice* (1910) he lent his support to reform of the penal system, while Harley Granville-Barker, whose revolutionary approach to stage direction did much to change theatrical production in the period, dissected in *The Voysey Inheritance* (performed 1905, published 1909) and *Waste* (performed 1907, published 1909) the hypocrisies and deceit of upper-class and professional life.

Didactic literature

Many Edwardian novelists were similarly eager to explore the shortcomings of English social life. Wells—in *Love and Mr. Lewisham* (1900); *Kipps* (1905); *Ann Veronica* (1909), his pro-suffragette novel; and *The History of Mr. Polly* (1910)—captured the frustrations of lower- and middle-class existence, even though he relieved his accounts with many comic touches. In *Anna of the Five Towns* (1902) Arnold Bennett detailed the constrictions of provincial life among the self-made business classes in the area of England known as the Potteries; in *The Man of Property* (1906), the first volume of *The Forsyte Saga*, Galsworthy described the destructive possessiveness of the professional

bourgeoisie; and in *Where Angels Fear to Tread* (1905) and *The Longest Journey* (1907) E.M. Forster portrayed with irony the insensitivity, self-repression, and philistinism of the English middle classes.

These novelists, however, wrote more memorably when they allowed themselves a larger perspective. In *The Old Wives' Tale* (1908) Bennett showed the destructive effects of time on the lives of individuals and communities and evoked a quality of pathos that he never matched in his other fiction; in *Tono-Bungay* (1909) Wells showed the ominous consequences of the uncontrolled developments taking place within a British society still dependent upon the institutions of a long-defunct landed aristocracy; and in *Howards End* (1910) Forster showed how little the rootless and self-important world of contemporary commerce cared for the more rooted world of culture, although he acknowledged that commerce was a necessary evil. Nevertheless, even as they perceived the difficulties of the present, most Edwardian novelists, like their counterparts in the theatre, held firmly to the belief not only that constructive change was possible but also that this change could in some measure be advanced by their writing.

Revival of traditional forms

Other writers, including Thomas Hardy and Rudyard Kipling, who had established their reputations during the previous century, and Hilaire Belloc, G.K. Chesterton, and Edward Thomas, who established their reputations in the first decade of the new century, were less confident about the future and sought to revive the traditional forms—the ballad, the narrative poem, the satire, the fantasy, the topographical poem, and the essay—that in their view preserved traditional sentiments and perceptions. The revival of traditional forms in the late 19th and early 20th century was not a unique event. There have been many such revivals during the 20th century, and the traditional poetry of A.E. Housman (whose book *A Shropshire Lad*, originally published in 1896, enjoyed huge popular success during World War I), Walter de la Mare, John Masefield, Robert Graves, and Edmund Blunden represents an important and often neglected strand of English literature in the first half of the century.

The most significant writing of the period, traditionalist or modern, was inspired by neither hope nor apprehension but by bleaker feelings that the new century would witness the collapse of a whole civilization. The new century had begun with Great Britain involved in the South African War (the Boer War; 1899–1902), and it seemed to some that the British Empire was as doomed to destruction, both from within and from without, as had been the Roman Empire. In his poems on the South African War, Hardy (whose achievement as a poet in the 20th century rivaled his achievement as a novelist in the 19th) questioned simply and sardonically the human cost of empire building and established a tone and style that many British poets were to use in the course of the century, while Kipling, who had done much to engender pride in empire, began to speak in his verse and short stories of the burden of empire and the tribulations it would bring.

James's sense of an imperial civilization in decline

No one captured the sense of an imperial civilization in decline more fully or subtly than the expatriate American novelist Henry James. In *The Portrait of a Lady* (1881) he had briefly anatomized the fatal loss of energy of the English ruling class and in *The Princess Casamassima* (1886) had described more directly the various instabilities that threatened its paternalistic rule. He did so with regret: the patrician American admired in the English upper class its sense of moral obligation to the community. By the turn of the century, however, he had noted a disturbing change. In *The Spoils of Poynton* (1897) and *What Maisie Knew* (1897) members of the upper class no longer seem troubled by the means adopted to achieve their morally dubious ends. Great Britain had become indistinguishable from the other nations of the Old World, in which an ugly rapacity had never been far from the surface. James's dismay at this condition gave to his subtle and compressed late fiction, *The Wings of the Dove* (1902), *The Ambassadors* (1903), and *The Golden Bowl* (1904), much of its gravity and air of disenchantment.

James's awareness of crisis affected the very form and style of his writing, for he was no longer assured that the world about which he wrote was either coherent in itself or unambiguously intelligible to its inhabitants. His fiction still presented characters within an identifiable social world, but he found his characters and their world increasingly elusive and enigmatic and his own grasp upon them, as he made clear in *The Sacred Fount* (1901), the questionable consequence of artistic will.

Another expatriate novelist, Joseph Conrad (pseudonym of Józef Teodor Konrad Korzeniowski, born in the Ukraine of Polish parents), shared James's sense of crisis but attributed it less to the decline of a specific civilization than to the failings of mankind itself. Man was a solitary, romantic creature of will who at any cost imposed his meaning upon the world because he could not endure a world that did not reflect his central place within it. In *Almayer's Folly* (1895) and *Lord Jim* (1900) he had seemed to sympathize with this predicament; but in "Heart of Darkness" (1902), *Nostromo* (1904), *The Secret Agent* (1907), and *Under Western Eyes* (1911) he detailed such imposition, and the psychological pathologies he increasingly associated with it, without sympathy. He did so as a philosophical novelist whose concern with the mocking limits of human knowledge affected not only the content of his fiction but also its very structure. His writing itself is marked by gaps in the narrative, by narrators who do not fully grasp the significance of the events they are retelling, and by characters who are unable to make themselves understood. James and Conrad used many of the conventions of 19th-century realism but transformed them to express what are considered to be peculiarly 20th-century preoccupations and anxieties.

The modernist revolution. *Anglo-American modernism: Pound, Lewis, Lawrence, and Eliot.* From 1908 to 1914 there was a remarkably productive period of innovation and experiment as novelists and poets undertook, in anthologies and magazines, to challenge the literary conventions not just of the recent past but of the entire Post-Romantic era. For a brief moment, London, which up to that point had been culturally one of the dullest of the European capitals, boasted an avant-garde to rival those of Paris, Vienna, and Berlin, even if its leading personality, Ezra Pound, and many of its most notable figures were American.

London's avant-garde

The spirit of modernism—a radical and utopian spirit stimulated by new ideas in anthropology, psychology, philosophy, political theory, and psychoanalysis—was in the air, expressed rather mutedly by the pastoral and often anti-modern poets of the Georgian movement (1912–22) and more authentically by the English and American poets of the Imagist movement, to which Pound first drew attention in *Ripostes* (1912), a volume of his own poetry, and in *Des Imagistes* (1914), an anthology. Prominent among the Imagists were the English poets T.E. Hulme, F.S. Flint, and Richard Aldington and the Americans Hilda Doolittle (H.D.) and Amy Lowell.

Reacting against what they considered to be an exhausted poetic tradition, the Imagists wanted to refine the language of poetry in order to make it a vehicle not for pastoral sentiment or imperialistic rhetoric but for the exact description and evocation of mood. To this end they experimented with free or irregular verse and made the image their principal instrument. In contrast to the leisurely Georgians, they worked with brief and economical forms.

Meanwhile, painters and sculptors, grouped together by the painter and writer Wyndham Lewis under the banner of vorticism, combined the abstract art of the Cubists with the example of the Italian Futurists who conveyed in their painting, sculpture, and literature the new sensations of movement and scale associated with such modern developments as automobiles and airplanes. With the typographically arresting *Blast: Review of the Great English Vortex* (two editions, 1914 and 1915) vorticism found its polemical mouthpiece and in its editor, Wyndham Lewis, its most active propagandist and accomplished literary exponent. His experimental play *Enemy of the Stars*, published in *Blast* in 1914, and his experimental novel *Tarr* (1918) can still surprise with their violent exuberance.

World War I brought this first period of the modernist revolution to an end and, while not destroying its radical

and utopian impulse, made the Anglo-American modernists all too aware of the gulf between their ideals and the chaos of the present. Novelists and poets parodied received forms and styles, in their view made redundant by the immensity and horror of the war, but, as can be seen most clearly in Pound's angry and satirical *Hugh Selwyn Mauberley* (1920), with a note of anguish and with the wish that writers might again make form and style the bearers of authentic meanings.

Lawrence and Eliot on the sickness of modern civilization

In his two most innovative novels, *The Rainbow* (1915) and *Women in Love* (1920), D.H. Lawrence traced the sickness of modern civilization—a civilization in his view only too eager to participate in the mass slaughter of the war—to the effects of industrialization upon the human psyche. Yet as he rejected the conventions of the fictional tradition, which he had used to brilliant effect in his deeply-felt autobiographical novel of working-class family life, *Sons and Lovers* (1913), he drew upon myth and symbol to hold out the hope that individual and collective rebirth could come through human intensity and passion.

On the other hand, the poet and playwright T.S. Eliot, another American resident in London, in his most innovative poetry, *Prufrock and Other Observations* (1917) and *The Waste Land* (1922), traced the sickness of modern civilization—a civilization that, on the evidence of the war, preferred death or death-in-life to life—to the spiritual emptiness and rootlessness of modern existence. As he rejected the conventions of the poetic tradition, Eliot, like Lawrence, drew upon myth and symbol to hold out the hope of individual and collective rebirth, but he differed sharply from Lawrence by supposing that rebirth could come through self-denial and self-abnegation. Even so, their satirical intensity, no less than the seriousness and scope of their analyses of the failings of a civilization that had voluntarily entered upon the first World War, ensured that Lawrence and Eliot became the leading and most authoritative figures of Anglo-American modernism in England in the whole of the postwar period.

During the 1920s, Lawrence (who left England in 1919) and Eliot began to develop viewpoints at odds with the reputations they had established through their early work. In *Kangaroo* (1923) and *The Plumed Serpent* (1926) Lawrence revealed the attraction to him of charismatic, masculine leadership, while in *For Lancelot Andrewes: Essays on Style and Order* (1928) Eliot (whose influence as a literary critic now rivaled his influence as a poet) announced that he was a "classicist in literature, royalist in politics and anglo-catholic in religion" and committed himself to hierarchy and order. Elitist and paternalistic, they did not, however, adopt the extreme positions of Pound (who left England in 1920 and settled permanently in Italy in 1925) or Lewis. Drawing upon the ideas of the left and of the right, Pound and Lewis dismissed democracy as a sham and argued that economic and ideological manipulation was the dominant factor. For some the antidemocratic views of the Anglo-American modernists simply made explicit the reactionary tendencies inherent in the movement from its beginning; for others they came from a tragic loss of balance occasioned by World War I. This issue is a complex one, and judgments upon the literary merit and political status of Pound's ambitious but immensely difficult imagist epic *The Cantos* (1917–70) and Lewis' powerful sequence of politico-theological novels *The Human Age* (*The Childermass,* 1928; *Monstre Gai* and *Malign Fiesta,* both 1955) are sharply divided.

Celtic modernism: Yeats, Joyce, Jones, and MacDiarmid. Pound, Lewis, Lawrence, and Eliot were the principal figures of Anglo-American modernism, but important contributions also were made by the Irish poet and playwright William Butler Yeats and the Irish novelist James Joyce. By virtue of nationality, residence, and, in Yeats's case, an unjust reputation as a poet still steeped in Celtic mythology, they had less immediate impact upon the British literary intelligentsia in the late 1910s and early 1920s than Pound, Lewis, Lawrence, and Eliot, although by the mid-1920s their influence had become direct and substantial. Many contemporary critics argue that Yeats's work as a poet and Joyce's work as a novelist are the most important modernist achievements of the period.

In his early verse and drama Yeats, who had been influenced as a young man by the Romantic and Pre-Raphaelite movements, evoked a legendary and supernatural Ireland in language that was often vague and grandiloquent. As an adherent of the cause of Irish nationalism he had hoped to instill pride in the Irish past. The poetry of *The Green Helmet* (1910) and *Responsibilities* (1914), however, was marked not only by a more concrete and colloquial style but also by a growing isolation from the nationalist movement, for Yeats celebrated an aristocratic Ireland epitomized for him by the family and country house of his friend and patron, Lady Gregory.

The grandeur of his mature reflective poetry in *The Wild Swans at Coole* (1917), *Michael Robartes and the Dancer* (1921), *The Tower* (1928), and *The Winding Stair* (1929) derived in large measure from the way in which (caught up by the violent discords of contemporary Irish history) he accepted the fact that his idealized Ireland was illusory. At its best his mature style combined passion and precision with powerful symbol, strong rhythm, and lucid diction; and even though his poetry often touched upon public themes, he never ceased to reflect upon the Romantic themes of creativity, selfhood, and the individual's relationship to nature, time, and history.

Joyce, who spent his adult life on the continent of Europe, expressed in his fiction his sense of the limits and possibilities of the Ireland he had left behind. In his collection of short stories, *Dubliners* (1914), and his largely autobiographical novel, *A Portrait of the Artist as a Young Man* (1916), he described in fiction at once realist and symbolist the individual cost of the sexual and imaginative oppressiveness of life in Ireland. As if by provocative contrast, his panoramic novel of urban life, *Ulysses* (1922), was sexually frank and imaginatively profuse. (Copies of the first edition were burned by the New York postal authorities, and British customs officials seized the second edition in 1923.) Employing extraordinary formal and linguistic inventiveness, including the so-called stream-of-consciousness method, Joyce depicted the experiences and the fantasies of various men and women in Dublin on a summer's day in June 1904. Yet his purpose was not simply documentary, for he drew upon an encyclopaedic range of European literature to stress the rich universality of life buried beneath the provincialism of pre-independence Dublin, still in 1904 a city within the British Empire. In his even more experimental *Finnegans Wake* (1939), extracts of which had already appeared as *Work in Progress* from 1928 to 1937, Joyce's commitment to cultural universality became absolute. By means of a strange, polyglot idiom of puns and portmanteau words he not only explored the relationship between the conscious and the unconscious but also suggested that the languages and myths of Ireland were interwoven with the languages and myths of many other cultures.

Joyce's inventive fiction

The example of Joyce's experimentalism was followed by the Anglo-Welsh poet David Jones and by the Scottish poet Hugh MacDiarmid (pseudonym of Christopher Murray Grieve). Whereas Jones concerned himself, in his complex and allusive poetry and prose, with the Celtic, Saxon, Roman, and Christian roots of Great Britain, MacDiarmid sought not only to recover what he considered to be an authentically Scottish culture but also to establish, as in his *In Memoriam James Joyce* (1955), the truly cosmopolitan nature of Celtic consciousness and achievement. MacDiarmid's masterpiece in the vernacular, *A Drunk Man Looks at the Thistle* (1926), helped to inspire the Scottish renaissance of the 1920s and '30s.

The literature of World War I and the interwar period. The impact of World War I upon the Anglo-American modernists has been noted. In addition the war brought a variety of responses from the more traditionalist writers, predominantly poets, who saw action. Rupert Brooke caught the idealism of the opening months of the war (and died in service); Siegfried Sassoon and Ivor Gurney caught the mounting anger and sense of waste as the war continued; and Isaac Rosenberg (perhaps the most original of the war poets), Wilfrid Owen, and Edmund Blunden not only caught the comradely compassion of the trenches but also addressed themselves to the larger moral

perplexities raised by the war (Rosenberg and Owen were killed in action).

Cynicism in the postwar years

It was not until the 1930s, however, that much of this poetry became widely known. In the wake of the war the dominant tone, at once cynical and bewildered, was set by Aldous Huxley's satirical novel *Crome Yellow* (1921). Drawing upon Lawrence and Eliot, he concerned himself in his novels of ideas—*Antic Hay* (1923), *Those Barren Leaves* (1925), and *Point Counter Point* (1928)—with the fate of the individual in rootless modernity. His pessimistic vision found its most complete expression in the 1930s, however, in his most famous and inventive novel, the anti-utopian fantasy *Brave New World* (1932), and his account of the anxieties of middle-class intellectuals of the period, *Eyeless in Gaza* (1936).

Huxley's frank and disillusioned manner was echoed by the poet Robert Graves in his autobiography, *Good-bye to All That* (1929), and by the poet Richard Aldington in his *Death of a Hero* (1929), a semiautobiographical novel of prewar bohemian London and the trenches. Exceptions to this dominant mood were found among writers too old to consider themselves, as did Graves and Aldington, members of a betrayed generation. In *A Passage to India* (1924) E.M. Forster examined the quest for and failure of human understanding among various ethnic and social groups in India under British rule. In *Parade's End* (1950; comprising *Some Do Not,* 1924; *No More Parades,* 1925; *A Man Could Stand Up,* 1926; and *Last Post,* 1928) Ford Madox Ford, with an obvious debt to James and Conrad, examined the demise of aristocratic England in the course of the war, exploring on a larger scale the themes he had treated with brilliant economy in his short novel *The Good Soldier* (1915). And in *Wolf Solent* (1929) and *A Glastonbury Romance* (1932), John Cowper Powys developed an eccentric and highly erotic mysticism.

These were, however, writers of an earlier, more confident era. A younger and more contemporary voice belonged to members of the Bloomsbury group. Setting themselves against the humbug and hypocrisy that, they believed, had marked their parents' generation in upper-class England, they aimed to be uncompromisingly honest in personal and artistic life. In Lytton Strachey's iconoclastic biographical study *Eminent Victorians* (1918) this amounted to little more than amusing irreverence, even though Strachey had a profound effect upon the writing of biography; but in the fiction of Virginia Woolf the rewards of this outlook were both profound and moving. In short stories and novels of great delicacy and lyrical power she set out to portray the limitations of the self, caught as it is in time, and suggested that these could be transcended, if only momentarily, by engagement with another self, a place, or a work of art. This preoccupation not only charged the act of reading and writing with unusual significance but also produced, in *To the Lighthouse* (1927), *The Waves* (1931)—perhaps her most inventive and complex novel—and *Between the Acts* (1941), her most sombre and moving work, some of the most daring fiction produced in the 20th century.

Virginia Woolf's fiction and essays

Woolf believed that her viewpoint offered an alternative to the destructive egotism of the masculine mind, an egotism that had found its outlet in World War I, but she did not consider this viewpoint, as she made clear in her essay *A Room of One's Own* (1929), to be the unique possession of women. In her fiction she presented men who possessed what she held to be feminine characteristics, a regard for others and an awareness of the multiplicity of experience; but she remained pessimistic about women gaining positions of influence, even though she set out the desirability of this in her feminist study *Three Guineas* (1938). Together with Joyce, who greatly influenced her *Mrs. Dalloway* (1925), Woolf transformed the treatment of subjectivity, time, and history in fiction and helped create a feeling among her contemporaries that traditional forms of fiction—with their frequent indifference to the mysterious and inchoate inner life of characters—were no longer adequate. Her eminence as a literary critic and essayist did much to foster an interest in the writing of other significant women novelists, such as Katherine Mansfield and Dorothy Richardson.

The 1930s. World War I created a profound sense of crisis in English culture, and this became even more intense with the worldwide economic collapse of the late 1920s and early '30s, the rise of Fascism, the Spanish Civil War (1936–39), and the approach of another full-scale conflict in Europe. It is not surprising, therefore, that much of the writing of the 1930s was bleak and pessimistic: even Evelyn Waugh's sharp and amusing satire on contemporary England, *Vile Bodies* (1930), ended with another, more disastrous war.

Divisions of class and the burden of sexual repression became common and interrelated themes in the fiction of the 1930s, a fiction that largely neglected the modernist revolution in technique of the 1920s and returned to the realist modes of the first decade of the century. In *A Scots Quair* (*Sunset Song,* 1932; *Cloud Howe,* 1933; and *Grey Granite,* 1934) the novelist Lewis Grassic Gibbon (pseudonym of James Leslie Mitchell) gives a panoramic account of Scottish rural and working-class life. The work resembles Lawrence's novel *The Rainbow* in its historical sweep and intensity of vision. Walter Greenwood's *Love on the Dole* (1933) is a bleak record, in the manner of Bennett, of the economic depression in a northern working-class community; and Graham Greene's *It's a Battlefield* (1934) and *Brighton Rock* (1938) are desolate studies, in the manner of Conrad, of the loneliness and guilt of men and women trapped in a contemporary England of conflict and decay. *A Clergyman's Daughter* (1935) and *Keep the Aspidistra Flying* (1936), by George Orwell, are evocations, in the manner of Wells and, in the latter case unsuccessfully, of Joyce, of contemporary lower middle-class existence, and *The Road to Wigan Pier* (1937) is a report of northern working-class mores. Elizabeth Bowen's *Death of the Heart* (1938) is a sardonic analysis, in the manner of James, of contemporary upper-class values.

Realist modes of the 1930s

Yet the most interesting writing of the decade grew out of the determination to supplement the diagnosis of class division and sexual repression with their cure. It was no accident that the poetry of W.H. Auden and his Oxford contemporaries, C. Day-Lewis, Louis MacNeice, and Stephen (later Sir Stephen) Spender, became quickly identified as the authentic voice of the new generation, for it matched despair with defiance. These self-styled prophets of a new world envisaged freedom from the bourgeois order being achieved in various ways. For Day-Lewis and Spender technology held out particular promise. This, allied to Marxist precepts, would in their view bring an end to poverty and the suffering it caused. For Auden especially, sexual repression was the enemy, and here the writings of Sigmund Freud and D.H. Lawrence were valuable. Whatever their individual preoccupations, these poets produced in the very play of their poetry, with its mastery of different genres, its rapid shifts of tone and mood, and its strange juxtapositions of the colloquial and esoteric, a blend of seriousness and high spirits irresistible to their peers.

The adventurousness of the new generation was shown, in part, by its love of travel (as in Christopher Isherwood's novels *Mr. Norris Changes Trains* [1935] and *Goodbye to Berlin* [1939], which reflect his experiences of postwar Germany); in part by its readiness for political involvement; and in part by its openness to the writing of the avant-garde of the Continent. The verse dramas coauthored by Auden and Isherwood, of which *The Ascent of F6* (1936) is the most notable, owed much to Bertolt Brecht; the political parables of Rex Warner, of which *The Aerodrome* (1941) is the most accomplished, owed much to Franz Kafka; and the complex and often obscure poetry of David Gascoyne and Dylan Thomas owed much to the Surrealists. Even so, Yeats's mature poetry and Eliot's *Waste Land,* with its parodies, its satirical edge, its multiplicity of styles, and its quest for spiritual renewal, provided the most significant models and inspiration for the young writers of the period. On the whole, however, despite the breadth, diversity, and liveliness of the writing of the 1930s, the decade was not one of great originality or innovation but rather one of imitation and emulation.

The literature of World War II (1939–45). The outbreak of war in 1939, as in 1914, brought to an end an era

of great intellectual and creative exuberance. Individuals were dispersed; the rationing of paper affected the production of magazines and books; and the poem and the short story, convenient forms for men under arms, became the favoured means of literary expression. It was hardly a time for new beginnings, although the poets of the New Apocalypse movement produced three anthologies (1940–45) inspired by neo-Romantic anarchism. No important new novelists or playwrights appeared, and only three new poets (all of whom died on active service) showed promise: Alun Lewis, Sidney Keyes, and Keith Douglas, the most gifted and distinctive, whose eerily detached accounts of the battlefield revealed a poet of potential greatness.

Eliot's *Four Quartets*

It was a poet of an earlier generation, T.S. Eliot, who produced in his *Four Quartets* (1935–42; published as a whole, 1943) the masterpiece of the war. Reflecting upon language, time, and history, he searched, in the three quartets written during the war, for moral and religious significance in the midst of destruction and strove to counter the spirit of nationalism inevitably present in a nation at war. The creativity that had seemed to end with the tortured religious poetry and verse drama of the 1920s and '30s had a rich and extraordinary late flowering as Eliot concerned himself, on the scale of *The Waste Land* but in a very different manner and mood, with the well-being of the society in which he lived. (H.A.Da.)

LITERATURE AFTER 1945

Increased attachment to religion most immediately characterized literature after World War II. This was particularly perceptible in authors who had already established themselves before the war. W.H. Auden turned from Marxist politics to Christian commitment, expressed in poems that attractively combine classical form with vernacular relaxedness. Christian belief suffused the verse plays of T.S. Eliot and Christopher Fry. While Graham Greene continued his powerful merging of thriller plots with studies of moral and psychological ambiguity, his Roman Catholicism loomed especially large in novels such as *The Heart of the Matter* (1948) and *The End of the Affair* (1951). Evelyn Waugh's *Brideshead Revisited* (1945) and his *Sword of Honour* trilogy (1965; published separately as *Men at Arms* [1952], *Officers and Gentlemen* [1955], and *Unconditional Surrender* [1961]) venerate Roman Catholicism as the repository of values seen as threatened by democracy. Spiritual solace was found in Eastern mysticism by Aldous Huxley and Christopher Isherwood, and by Robert Graves, behind whose taut, graceful lyric poetry lay the creed he expressed in *The White Goddess* (1948), a matriarchal mythology revering the female principle.

Golding and Spark

Fiction. The two most innovatory novelists to begin their careers soon after World War II were also religious believers—William Golding and Muriel Spark. In novels of poetic compactness they frequently return to the notion of original sin as they transfigure small communities into microcosms. In Golding's first novel, *Lord of the Flies* (1954), schoolboys cast away on a Pacific island during a nuclear war reenact humanity's fall from grace. Spark's best-known novel, *The Prime of Miss Jean Brodie* (1961), makes events in a 1930s Edinburgh classroom replicate, in miniature, the rise of fascism in Europe.

Lord of the Flies has affinities with George Orwell's examinations of totalitarian nightmare, the fable *Animal Farm* (1945) and the novel *Nineteen Eighty-four* (1949). Spark's astringent portrayal of behaviour in confined little worlds is partly indebted to Dame Ivy Compton-Burnett, who, from the 1920s to the 1970s, produced a remarkable series of novels written almost entirely in mordantly witty dialogue and dramatizing tyranny and power struggles in secluded late Victorian households. The stylized novels of Henry Green also seem to be precursors of the terse, compressed fiction that Spark and Golding brought to such distinction. This kind of fiction, it was argued by Iris Murdoch, a philosopher as well as a novelist, ran antiliberal risks in its preference for allegory, pattern, and symbol over the social capaciousness and realistic rendition of character at which the great 19th-century novels excelled. Murdoch's own fiction, typically engaged with themes of goodness, authenticity, selfishness, and altruism, oscillates between these two modes of writing. *A Severed Head* (1961) is the most incisive and entertaining of her elaborately artificial works; *The Bell* (1958) best achieves the psychological and emotional complexity she found so valuable in classic 19th-century fiction.

While restricting themselves to socially limited canvases, novelists such as Elizabeth Bowen, Elizabeth Taylor, and Barbara Pym continued the tradition of depicting emotional and psychological nuance that Murdoch felt was dangerously neglected in mid-20th-century novels. In contrast to their wry comedies of sense and sensibility, and to the packed parables of Golding and Spark, was yet another type of fiction, produced by a group of writers who became known as the Angry Young Men. From authors such as John Braine, John Wain, Alan Sillitoe, Stan Barstow, and David Storey (also a significant dramatist) came a spate of novels often ruggedly autobiographical in origin and near documentary in approach. Their predominant subject was social mobility, usually from the northern working class to the southern middle class. Social mobility was also inspected, from an upper-class vantage point, in Anthony Powell's Proustian 12-novel sequence *A Dance to the Music of Time* (1951–75). Satiric watchfulness of social change was also the specialty of Kingsley Amis, who derided the reactionary and the pompous in his first novel, *Lucky Jim* (1954). As Amis grew older, his irascibility vehemently swiveled toward left-wing and progressive targets, and he established himself as a Tory satirist in the vein of Waugh or Powell. C.P. Snow's earnest 11-novel sequence, *Strangers and Brothers* (1940–70), about a man's journey from the provincial lower classes to London's "corridors of power," had its admirers. But the most inspired fictional cavalcade of social and cultural life in 20th-century Britain was Angus Wilson's *No Laughing Matter* (1967), a book that set a triumphant seal on his progress from a writer of acidic short stories to a major novelist whose work unites 19th-century breadth and gusto with 20th-century formal versatility and experiment.

The Angry Young Men

The parody and pastiche that Wilson brilliantly deploys in *No Laughing Matter* and the book's fascination with the sources and resources of creativity constitute a rich, imaginative response to a growing self-consciousness about the form of the novel and relationships between past and present fiction that showed itself most stimulatingly in the works of the academically based novelists Malcolm Bradbury and David Lodge.

From the late 1960s onward the outstanding trend in fiction was enthrallment with empire. The first phase of this focused on imperial disillusion and dissolution. In his vast, detailed *Raj Quartet* (1966–75), Paul Scott charts the last years of the British in India; he followed it with *Staying On* (1977), a poignant comedy about those who remained after independence. Three half-satiric, half-elegiac novels by J.G. Farrell (*Troubles* [1970], *The Siege of Krishnapur* [1973], and *The Singapore Grip* [1978]) likewise spotlighted imperial discomfiture. Then, in the 1980s, postcolonial voices made themselves audible. Salman Rushdie's crowded comic saga about the generation born as Indian independence dawned, *Midnight's Children* (1981), boisterously mingles material from Eastern fable, Hindu myth, Islāmic lore, Bombay cinema, cartoon strips, advertising billboards, and Latin American magic realism. (Such eclecticism, sometimes called "postmodern," also showed itself in other kinds of fiction in the 1980s. Julian Barnes's *A History of the World in 10½ Chapters* [1989], for example, inventively mixes fact and fantasy, reportage, art criticism, autobiography, parable, and pastiche in its working of fictional variations on the Noah's ark myth.) For Rushdie, as further demonstrated by such novels as *The Satanic Verses* (1988) and *The Ground Beneath Her Feet* (1999), stylistic miscellaneousness—a way of writing that exhibits the vitalizing effects of cultural cross-fertilization—is especially suited to conveying postcolonial experience. (The Iranian leader Ayatollah Ruhollah Khomeini pronounced a *fatwa*, in effect a death sentence [later suspended], on Rushdie for his supposed blasphemy in *The Satanic Verses*.) However, not all postcolonial authors followed Rushdie's example. Vikram Seth's massive novel about India after independence, *A Suitable Boy* (1993), is

Post-colonial voices

a prodigious feat of realism, resembling 19th-century novels. Nor was India alone in inspiring vigorous postcolonial writing. Timothy Mo's novels report on colonial predicaments in East Asia with a political acumen reminiscent of Conrad. Particularly notable is *An Insular Possession* (1986), which vividly harks back to the founding of Hong Kong. Kazuo Ishiguro's spare, refined novel *An Artist of the Floating World* (1986) records how a painter's life and work became insidiously coarsened by the imperialistic ethos of 1930s Japan. Novelists such as Buchi Emecheta and Ben Okri wrote of postcolonial Africa, as did V.S. Naipaul in his most ambitious novel, *A Bend in the River* (1979). Naipaul also chronicled aftermaths of empire around the globe and particularly in his native Caribbean. Nearer England, the strife in Northern Ireland provoked fictional response, among which the bleak, graceful novels and short stories of William Trevor and Bernard MacLaverty stand out.

Widening social divides in 1980s Britain were also registered in fiction, sometimes in works that purposefully imitated the Victorian "Condition of England" novel (the best is David Lodge's elegant, ironic *Nice Work* [1988]). The most thoroughgoing of such panoramas of an England cleft by regional gulfs and gross inequities is Margaret Drabble's *The Radiant Way* (1987). With less documentary substantiality, Martin Amis's novels (for example, *Money* [1984]) are angled somewhere between scabrous relish and satiric disgust.

Feminist novelists

Just as some postcolonial novelists used myth, magic, and fable as a stylistic throwing-off of Anglo-Saxon realistic fiction, so numerous feminist novelists took to Gothic, fairy tale, and fantasy as counter-effects to the "patriarchal discourse" of rationality, logic, and linear narrative. The most gifted exponent of this kind of writing was Angela Carter, whose exotic and erotic imagination unrolled most eerily and resplendently in her short-story collection *The Bloody Chamber and Other Stories* (1979). Jeanette Winterson also wrote in this vein. Having distinguished herself earlier in a realistic mode, as had authors such as Drabble and Pat Barker, Doris Lessing published a sequence of science-fiction novels about issues of gender and colonialism, *Canopus in Argos—Archives* (1979–83).

In the 1980s and '90s an urge in fiction to look backward was widely evident. The historical novel enjoyed an exceptional heyday. One of its outstanding practitioners was Barry Unsworth, the settings of whose works range from the Ottoman Empire to Venice in its imperial prime as well as to northern England in the 14th century (*Morality Play* [1995]). Patrick O'Brian attracted a keen following with his series of meticulously researched novels about naval life during the Napoleonic era, the 20-book-long sequence ending with *Blue at the Mizzen* in 1999. Beryl Bainbridge, who began her fictional career as a writer of quirky black comedies about British northern provincial life, turned her attention to Victorian and Edwardian misadventures in such works as *The Birthday Boys* (1991), which retraced Captain Robert Falcon Scott's doomed expedition to the South Pole.

Many novels juxtaposed a present-day narrative with one set in the past. A.S. Byatt's *Possession* (1990) did so with particular intelligence. It also made extensive use of period pastiche, another enthusiasm of novelists toward the end of the 20th century. Adam Thorpe's striking first novel, *Ulverton* (1992), records the 300-year history of a fictional village in the styles of different epochs. William Golding's veteran fictional career came to a bravura conclusion with a trilogy whose story is told by an early 19th-century narrator (*To the Ends of the Earth* [1991]). In addition to the interest in history, a concern with tracing aftereffects was strongly present in fiction. Most subtly and powerfully exhibiting this, Ian McEwan—who came to notice in the 1970s as an unnervingly emotionless observer of contemporary decadence—grew into imaginative maturity with novels largely set in Berlin in the 1950s (*The Innocent* [1990]) and in Europe in 1946 (*Black Dogs* [1992]). Their scenes of the 1990s were haunted by what were perceived as the continuing repercussions of World War II. These repercussions were also felt in *Last Orders* (1996), a masterpiece of quiet authenticity by Graham Swift.

Poetry. The last flickerings of New Apocalypse poetry—the flamboyant, surreal, and rhetorical style favoured by Dylan Thomas, George Barker, David Gascoyne, and Vernon Watkins—died away soon after World War II. In its place emerged what came to be known with characteristic understatement as The Movement. Poets such as D.J. Enright, Donald Davie, John Wain, Roy Fuller, Robert Conquest, and Elizabeth Jennings produced urbane, formally disciplined verse characterized by irony, understatement, and a sardonic refusal to strike attitudes or make grand claims for the poet's role. The preeminent practitioner of this style was Philip Larkin, who had earlier displayed some of its qualities in two novels. In Larkin's poetry (*The Less Deceived* [1955], *The Whitsun Weddings* [1964], *High Windows* [1974]) a melancholy sense of life's limitations throbs through lines of elegiac elegance. Suffused with acute awareness of mortality and transience, his poetry is also finely responsive to natural beauty, vistas of which open up even in poems darkened by fear of death or sombre preoccupation with human solitude. John Betjeman, poet laureate from 1972 to 1984, shared both Larkin's intense consciousness of mortality and his gracefully versified nostalgia for 19th- and early 20th-century life.

The Movement

In contrast to the rueful traditionalism of their work is the poetry of Ted Hughes, who succeeded Betjeman as poet laureate in 1984. In extraordinarily vigorous verse, beginning with his first collection, *The Hawk in the Rain* (1957), Hughes captures the ferocity, vitality, and splendour of the natural world. In works such as *Crow* (1970) he adds a mythic dimension to his fascination with savagery (a fascination also apparent in the poetry Thom Gunn produced through the late 1950s and '60s). Much of Hughes's poetry is rooted in his experiences as a farmer (as in his collection *Moortown* [1979]). It also shows a deep receptivity to the way the contemporary world is underlain by strata of history. This realization, along with strong regional roots, is something Hughes had in common with a number of poets writing in the second half of the 20th century. The work of Geoffrey Hill (for example, *Tenebrae* [1978] and *The Triumph of Love* [1998]) treats Britain as a palimpsest whose superimposed layers of history are uncovered in poems, which are sometimes written in prose. Basil Bunting's *Briggflatts* (1966) celebrates his native Northumbria. The dour poems of R.S. Thomas commemorate a harsh rural Wales of remote hill farms. Britain's industrial regions received attention in poetry, too. In collections such as *Terry Street* (1969), Douglas Dunn wrote of working-class life in northeastern England. Tony Harrison, the most arresting English poet to find his voice in the later decades of the 20th century (among his collections are *Continuous* [1981] and *The Shadow of Hiroshima* [1995]), came from a working-class community in industrial Yorkshire. Harrison's social and cultural journey away from that world by means of a grammar school education and a degree in classics provoked responses in him that his poetry, trenchantly combining colloquial ruggedness with classic form, conveys with imaginative vehemence and caustic wit: anger at the deprivations and humiliations endured by the working class; guilt over the way his talent had lifted him away from these.

Also from Yorkshire was Blake Morrison, whose finest work, *The Ballad of the Yorkshire Ripper* (1987), was composed in taut, macabre stanzas thickened with dialect. Morrison's work also displayed a growing development in late 20th-century British poetry: the writing of narrative verse. Although there had been earlier instances of this verse after 1945 (John Betjeman's blank-verse autobiography *Summoned by Bells* [1960] proved the most popular), it was in the 1980s and '90s that the form was given renewed prominence by poets such as the Kipling-influenced James Fenton. An especially ambitious exercise in the narrative genre was Craig Raine's *History: The Home Movie* (1994), a huge semifictionalized saga, written in three-line stanzas, chronicling several generations of his own and his wife's families. Before this, books of dazzling virtuosity (including *Rich* [1984]) had established Raine as the founder, and most inventive exemplar, of what came to be called the Martian school of poetry. The defining characteristic of this school was a poetry rife with startling images, unex-

The Martian school of poetry

pected but audaciously apt similes, and rapid, imaginative tricks of transformation.

From the late 1960s onward Northern Ireland, convulsed by sectarian violence, was particularly prolific in poetry. From a cluster of considerable talents—Michael Longley, Derek Mahon, Medbh McGuckian, Paul Muldoon—Seamus Heaney soon stood out. Born into a Roman Catholic farming family in County Derry, he began by publishing verse—in his collections *Death of a Naturalist* (1966) and *Door into the Dark* (1969)—that combines a tangible, tough, sensuous response to rural and agricultural life, reminiscent of that of Ted Hughes, with meditation about the relationship between the taciturn world of his parents and his own communicative calling as a poet. Since then, in increasingly magisterial books of poetry—such as *Wintering Out* (1972), *The Haw Lantern* (1987), *The Spirit Level* (1996)—Heaney became one of the greatest poets Ireland has produced, eventually winning the Nobel Prize for Literature (1995). Having spent his formative years amid the murderous divisiveness of Ulster, he wrote poetry particularly distinguished by its fruitful bringing together of opposites. Sturdy familiarity with country life goes along with delicate stylistic accomplishment and sophisticated literary allusiveness. Surveying carnage, vengeance, bigotry, and gentler disjunctions such as that between the unschooled and the cultivated, Heaney made himself the master of a poetry of reconciliations.

Seamus Heaney

The closing years of the 20th century witnessed a remarkable last surge of creativity from Ted Hughes (after his death Andrew Motion, a writer of more subdued and subfusc verses, became poet laureate). In *Birthday Letters* (1998), Hughes published a poetic chronicle of his much-speculated-upon relationship with Sylvia Plath, the American poet who committed suicide in 1963. With *Tales from Ovid* (1997) and his versions of Aeschylus's *Oresteia* (1999) and Euripides's *Alcestis* (1999), he looked back even further. These works—part translation, part transformation—magnificently re-energize classic texts with Hughes's own imaginative powers and preoccupations. A similar feat was impressively effected by Seamus Heaney in his fine translation of *Beowulf* (1999).

Drama. Apart from the short-lived attempt by T.S. Eliot and Christopher Fry to bring about a renaissance of verse drama, theatre in the late 1940s and early 1950s was most notable for the continuing supremacy of the "well-made" play, which focused upon, and mainly attracted as its audience, the comfortable middle class. The most interesting playwright working within this mode was Terence Rattigan, whose carefully crafted, conventional-looking plays—such as *The Browning Version* (1948), *The Deep Blue Sea* (1952), and *Separate Tables* (1954)—affectingly disclose desperations, terrors, and emotional forlornness concealed behind reticence and gentility. In 1956 John Osborne's *Look Back in Anger* forcefully signaled the start of a very different dramatic tradition. Taking as its hero a furiously voluble working-class man and replacing staid mannerliness on stage with emotional rawness, sexual candour, and social rancour, *Look Back in Anger* initiated a move toward what critics called "kitchen-sink" drama. Shelagh Delaney (with her one influential play, *A Taste of Honey* [1958]) and Arnold Wesker (especially in his politically and socially engaged trilogy, *Chicken Soup with Barley* [1958], *Roots* [1959], and *I'm Talking About Jerusalem* [1960]) gave further impetus to this movement, as did Osborne in subsequent plays such as *The Entertainer* (1957), his attack on what he saw as the tawdriness of post-war Britain. Also working within this tradition was John Arden, whose theatrical devices emulate those of Bertold Brecht. Arden wrote historical plays, such as *Armstrong's Last Goodnight* (1964), to advance radical social and political views, providing a model that several later left-wing dramatists followed.

"Kitchen-sink" drama

An alternative reaction against drawing-room naturalism came from the Theatre of the Absurd. Through increasingly minimalist plays—from *Waiting for Godot* (1953) to such stark brevities as his 30-second-long drama, *Breath* (1969)—Samuel Beckett used character pared down to basic existential elements and symbol to reiterate his Stygian view of the human condition (something he also conveyed in similarly gaunt and allegorical novels such as *Molloy* [1951], *Malone Dies* [1958], and *The Unnamable* [1960], all originally written in French). Some of Beckett's themes and techniques are discernible in the drama of Harold Pinter. Characteristically concentrating on two or three people maneuvering for sexual or social superiority in a claustrophobic room, works such as *The Birthday Party* (1958), *The Homecoming* (1965), and *Moonlight* (1993) are potent dramas of menace in which a slightly surreal atmosphere contrasts with and undermines dialogue of tape-recorder authenticity. Joe Orton's anarchic black comedies—including *Entertaining Mr. Sloane* (1964) and *What the Butler Saw* (1969)—put theatrical procedures pioneered by Pinter at the service of outrageous sexual farce (something Pinter himself also showed a flair for in television plays such as *The Lover* [1963] and later stage works such as *Celebration* [2000]). Orton's taste for dialogue in the epigrammatic style of Oscar Wilde was shared by one of the wittiest dramatists to emerge in the 1960s, Tom Stoppard. In plays from *Rosencrantz and Guildenstern Are Dead* (1966) to later triumphs such as *Arcadia* (1993) and *The Invention of Love* (1997), Stoppard set intellectually challenging concepts ricocheting in scenes glinting with the to-and-fro of polished repartee. The most prolific comic playwright from the 1960s onward was Alan Ayckbourn, whose virtuoso feats of stagecraft and theatrical ingenuity made him one of Britain's most popular dramatists. Ayckbourn's plays showed an increasing tendency to broach darker themes and were especially scathing (for instance, in *A Small Family Business* [1987]) on the topics of the greed and selfishness that he considered to have been promoted by Thatcherism, the prevailing political philosophy in 1980s Britain.

Irish drama also exhibited a propensity for combining comedy with something more sombre. Its most recurrent subject matter during the last decades of the 20th century was small-town provincial life. Brian Friel (*Dancing at Lughnasa* [1990]), Tom Murphy (among other plays, *Conversations on a Homecoming* [1985]), Martin McDonagh (*The Beauty Queen of Leenane* [1996]), and Conor McPherson (*The Weir* [1997]) all wrote effectively on this theme.

Playwrights who had much in common with John Arden's ideological beliefs and his admiration for Brechtian theatre—Edward Bond, Howard Barker, Howard Brenton—maintained a steady output of parable-like plays dramatizing radical left-wing doctrine. Their scenarios were remarkable for an uncompromising insistence on human cruelty and the oppressiveness and exploitativeness of capitalist class and social structures. In the 1980s agitprop theatre—antiestablishment, feminist, black, and gay—thrived. One of the more durable talents to emerge from it was Caryl Churchill, whose *Serious Money* (1987) savagely encapsulated the finance frenzy of the 1980s. David Edgar developed into a dramatist of impressive span and depth with plays such as *Pentecost* (1994), his masterly response to the collapse of communism and rise of nationalism in eastern Europe. David Hare similarly widened his range; in the 1990s he completed a panoramic trilogy surveying the contemporary state of British institutions such as the Anglican church (in *Racing Demon* [1990]).

Hare also wrote political plays for television, such as *Licking Hitler* (1978) and *Saigon: Year of the Cat* (1983). Trevor Griffiths, author of dialectical stage plays clamorous with debate, put television drama to the same use (*Comedians* [1975] had particular impact). Dennis Potter deployed a wide battery of the medium's resources to transmit his revulsion, semireligious in nature, at what he saw as widespread hypocrisy, sadism, and injustice in British society. Alan Bennett excelled in both stage and television drama. Bennett's first work for the theatre, *Forty Years On* (1968), was an expansive, mocking, and nostalgic cabaret of cultural and social change in England between and during the two world wars. His masterpieces, though, are dramatic monologues written for television—*A Woman of No Importance* (1982) and 12 works he called *Talking Heads* (1987) and *Talking Heads 2* (1998). In these television plays Bennett's comic genius for capturing the rich waywardness of everyday speech combines with

Plays for television

psychological acuteness, emotional delicacy, and a melancholy consciousness of life's transience. The result is a drama, simultaneously hilarious and sad, of exceptional distinction. Bennett's 1991 play, *The Madness of George III,* takes his fascination with England's past back to the 1780s and in doing so accords with the widespread mood of retrospection apparent in British literature at the turn of the 21st century. (P.Ke.)

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(P.Ke.)

Environmentalism and Environmental Law

Environmentalism is the political and philosophical movement that seeks to improve and protect the quality of the natural environment. It advocates, among other general goals, an end to or the amelioration of environmentally harmful activities by humans and the adoption of environmentally benign forms of political, economic, and social organization. At a minimum, environmentalists claim that the interests of living things other than humans, and the quality of the natural environment as a whole, are deserving of serious consideration in decision making about political, economic, and social policies.

As the environmental movement acquired a larger following and greater political influence from the mid-20th century, many Western countries enacted legislation to reduce or eliminate specific forms of environmental pollution within their borders, and international conferences, such as the 1972 United Nations Conference on the Human Environment, were held to negotiate multilateral agreements on global environmental problems. With the rapid growth of domestic and international legislation on environmental topics, the field of environmental law soon developed from a modest adjunct of the law of public-health regulation to an almost universally recognized independent body of law for protecting both human health and nonhuman nature.

This article treats the intellectual foundations of environmentalism and the history of the environmental movement, as well as the development and principal forms of environmental law. For a discussion of natural-resource conservation and management, see CONSERVATION OF NATURAL RESOURCES. For coverage of related topics in the *Macropædia* and the *Micropædia,* see the *Propædia,* sections 355, 521, 543, 544, 552, and 10/33.

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Environmentalism

INTELLECTUAL UNDERPINNINGS

Environmental philosophy and the various branches of the environmental movement are often classified into two schools of thought: anthropocentrism and biocentrism. This division has been described in other terminology as "shallow" ecology versus "deep" ecology and as "technocentrism" versus "ecocentrism." Anthropocentric, or "human-centred," approaches focus mainly on the negative effects that environmental degradation has on human beings and their interests, including their interests in health, recreation, and quality of life. It is often characterized by a mechanistic approach to nonhuman nature in which individual creatures and species have only an instrumental value for humans. The defining feature of anthropocentrism is that it considers the moral obligations humans have to the environment to derive from obligations that humans have to each other—and, less crucially, to future generations of humans—rather than from any obligation to other living things or to the environment as a whole. Human obligations to the environment are thus indirect.

Critics of anthropocentrism have charged that it amounts to a form of human "chauvinism." They argue that anthropocentric approaches presuppose the historically Western view of nature as merely a resource to be managed or exploited for human purposes. In contrast to anthropocentrism, biocentric, or "life-centred," approaches claim that nature has an intrinsic moral worth that does not depend on its usefulness to human beings, and it is this intrinsic worth that gives rise directly to obligations to the environment. Humans are therefore morally bound to protect the environment, as well as individual creatures and species, for their own sake. In this sense, biocentrics view human beings and other elements of the natural environment, both living and often nonliving, as members of a single moral and ecological community.

The division between anthropocentrism and biocentrism played a central role in the development of environmental thought in the late 20th century. Whereas some earlier movements, such as apocalyptic (survivalist) environmentalism and emancipatory environmentalism—as well as its offshoot, human-welfare ecology—were animated primarily by a concern for human well-being, later movements, including social ecology, deep ecology, the animal-rights and animal-liberation movements, and ecofeminism, focused on the moral worth of nonhuman nature.

Anthropocentric schools of thought. *Apocalyptic environmentalism.* The vision of the environmental movement of the 1960s and early '70s was generally pessimistic, reflecting a pervasive sense of "civilization malaise" and a conviction that the Earth's long-term prospects were bleak. Works such as Rachel Carson's *Silent Spring* (1962) suggested that the planetary ecosystem was reaching the limits of what it could sustain. This so-called apocalyptic, or survivalist, literature encouraged reluctant calls from some environmentalists for increasing the powers of centralized governments over human activities deemed environmentally harmful—a viewpoint expressed most vividly in Robert Heilbroner's *An Inquiry into the Human Prospect* (1974), which argued that human survival ultimately required the sacrifice of human freedom. Counterarguments, such as those presented in Julian Simon and Herman Kahn's *The Resourceful Earth* (1984), emphasized humanity's ability to find or to invent substitutes for resources that were scarce and in danger of being exhausted.

Rachel Carson's *Silent Spring*

Emancipatory environmentalism. Beginning in the 1970s, many environmentalists attempted to develop strategies for limiting environmental degradation through recycling, the use of alternative-energy technologies, the decentralization and democratization of economic and social planning and, for some, the reorganization of major industrial sectors, including the agriculture and energy industries. In contrast to apocalyptic environmentalism, so-called "emancipatory" environmentalism took a more positive and practical approach, one aspect of which was the effort to promote an ecological consciousness and an ethic of "stewardship" of the environment. One form of emancipatory environmentalism, human-welfare ecology, aimed to enhance human life by creating a safe and clean environment. It was part of a broader concern with distributive justice and reflected the tendency, later characterized as "postmaterialist," of citizens in advanced

industrial societies to place more importance on "quality-of-life" issues than on traditional economic concerns. Emancipatory environmentalism also was distinguished for some of its advocates by an emphasis on developing small-scale systems of economic production that would be more closely integrated with the natural processes of surrounding ecosystems. This more environmentally holistic approach to economic planning was promoted in work by the American ecologist Barry Commoner and by the German economist Ernst Friedrich Schumacher. In contrast to earlier thinkers who had downplayed the interconnectedness of natural systems, Commoner and Schumacher emphasized productive processes that worked with nature, not against it, encouraged the use of organic and renewable resources rather than synthetic products (*e.g.,* plastics and chemical fertilizers), and advocated renewable and small-scale energy resources (*e.g.,* wind and solar power) and government policies that supported effective public transportation and energy efficiency. The emancipatory approach was evoked through the 1990s in the popular slogan, "Think globally, act locally." Its small-scale, decentralized planning and production have been criticized, however, as unrealistic in highly urbanized and industrialized societies.

"Think globally, act locally"

Biocentric schools of thought. *Social ecology and deep ecology.* An emphasis on small-scale economic structures and the social dimensions of the ecological crisis also is a feature of the movement known as social ecology, whose major proponent is the American environmental anarchist Murray Bookchin. Social ecologists trace the causes of environmental degradation to the existence of unjust, hierarchical relationships in human society, which they see as endemic to the large-scale social structures of modern capitalist states. Accordingly, they argue that the most environmentally sympathetic form of political and social organization is one based on decentralized small-scale communities and systems of production.

A more radical doctrine, known as deep ecology, builds on preservationist themes from the early environmental movement. Its main originators, the Norwegian philosopher Arne Næss, the American sociologist Bill Devall, and the American philosopher George Sessions, share with social ecologists a distrust of capitalism and industrial technology and favour decentralized forms of social organization. Deep ecologists also claim that humans need to regain a "spiritual" relationship with nonhuman nature. The biocentric principle of interconnectedness was extensively developed by British environmentalist James Lovelock, who proposed in *Gaia: A New Look at Life on Earth* (1979) that the planet is a single living, self-regulating entity capable of reestablishing an ecological equilibrium, even without the existence of human life. Despite their emphasis on spirituality, some more extreme forms of deep ecology have been strongly criticized as antihumanist, on the ground that they entail opposition to famine relief and immigration and acceptance of large-scale losses of life caused by AIDS and other pandemics.

Animal rights. The emphasis on intrinsic value and the interconnectedness of nature was fundamental to the development of the animal-rights movement, whose activism was influenced by works such as Peter Singer's *Animal Liberation* (1977). Animal-rights approaches go beyond a concern with ill treatment and cruelty to animals, demanding an end to all forms of animal exploitation, including the use of animals in scientific and medical experiments and as sources of entertainment (*e.g.,* in circuses, rodeos, and races) and food.

Ecofeminism. Oppression, hierarchy, and spiritual relationships with nature also have been central concerns of ecofeminism. Ecofeminists assert that the destruction of nature by humans is connected to the oppression of women by men, in the sense that both arise from political theories and social practices in which nature and women are treated as objects to be owned or controlled. Ecofeminists aim to establish a central role for women in the pursuit of an environmentally sound and socially just society. They have been divided, however, over how to conceive of the relationship between nature and women, which they hold is more intimate and more "spiritual" than the relationship between nature and men. Whereas cultural ecofeminists argue that the relationship is inherent in women's reproductive and nurturing roles, social ecofeminists, while acknowledging the relationship's immediacy, claim that it arises from social and cultural hierarchies that confine women primarily to the private sphere.

HISTORY OF THE ENVIRONMENTAL MOVEMENT

Concern for the impact on human life of problems such as air and water pollution dates to at least Roman times. Pollution was associated with the spread of epidemic disease in Europe from the late 14th century to the mid-16th century, and soil conservation was practiced in China, India, and Peru as early as 2,000 years ago. But, in general, such concerns did not give rise to public activism.

Early conservation efforts. The contemporary environmental movement arose primarily from concerns in the late 19th century about the protection of the countryside in Europe and the wilderness in the United States and the health consequences of pollution during the Industrial Revolution. In opposition to liberalism—which held that all social problems, including environmental ones, could and should be solved through the free market—most early environmentalists believed that government rather than the market should be charged with protecting the environment and ensuring the conservation of resources. An early philosophy of resource conservation was developed by Gifford Pinchot (1865–1946), the first chief of the U.S. Forest Service, for whom conservation represented the wise and efficient use of resources. Also in the United States at about the same time, a more strongly biocentric approach arose in the preservationist philosophy of John Muir (1838–1914), founder of the Sierra Club, and Aldo Leopold (1887–1948), a professor of wildlife management who was pivotal in the designation of Gila National Forest in New Mexico in 1924 as America's first national wilderness area. Leopold introduced the concept of a land ethic, arguing that humans should transform themselves from conquerors of nature into citizens of it.

Environmental organizations established from the late 19th to the mid-20th century were primarily middle-class lobbying groups concerned with nature conservation, wildlife protection, and the pollution that arose from industrial development and urbanization. There were also scientific organizations concerned with natural history and with biological aspects of conservation efforts.

The environmental movement from the mid-20th century. Beginning in the 1960s, the various philosophical strands of environmentalism were given political expression through the establishment of "green" political movements in the form of activist nongovernmental organizations and environmentalist political parties. Despite the diversity of the environmental movement, four pillars provided a unifying theme to the broad goals of political ecology: protection of the environment, grassroots democracy, social justice, and nonviolence. However, for a small number of environmental groups and individual activists who engaged in ecoterrorism, violence was viewed as a justified response to what they considered the violent treatment of nature by some interests, particularly the logging and mining industries. The political goals of the contemporary environmental movement in the West focused on changing government policy and promoting environmental social values. In the developing world, environmentalism has been closely involved in "emancipatory" politics and grassroots activism on issues such as poverty, democratization, and political and human rights, including the rights of women and indigenous peoples.

Eco-terrorism

The early strategies of the contemporary environmental movement were self-consciously activist and unconventional, involving direct-protest actions designed to draw attention to environmentally harmful policies and projects. Other strategies included public-education and media campaigns, community-directed activities, and conventional lobbying of policy makers and political representatives. The movement also attempted to set public examples in order to increase awareness of and sensitivity to environmental issues. Such projects included recycling, green consumerism (also known as "buying green"), and the es-

tablishment of alternative communities, including self-sufficient farms, workers' cooperatives, and cooperative-housing projects.

Green political parties. The electoral strategies of the environmental movement included the nomination of environmental candidates and the registration of green political parties. These parties were conceived of as a new kind of political organization that would bring the influence of the grassroots environmental movement directly to bear on the machinery of government, make the environment a central concern of public policy, and render the institutions of the state more democratic, transparent, and accountable. The world's first green parties—the Values Party, a nationally based party in New Zealand, and the United Tasmania Group, organized in the Australian state of Tasmania—were founded in the early 1970s. Green parties also were established in the former Soviet bloc, where they were instrumental in the collapse of some communist regimes, and in some developing countries in Asia, South America, and Africa, though they have achieved little electoral success there.

The German Green Party

The most successful environmental party has been the German Green Party (die Grünen), founded in 1980. Although it failed to win representation in federal elections that year, it entered the Bundestag (parliament) in both 1983 and 1987, winning 5.6 percent and 8.4 percent of the national vote, respectively. In 1998 it formed a governing coalition with the Social Democratic Party, and the party's leader, Joschka Fischer, was appointed as the country's foreign minister.

Throughout the last two decades of the 20th century, green parties won national representation in a number of countries and even claimed the office of mayor in European capital cities such as Dublin and Rome in the mid-1990s. By this time green parties had become broad political vehicles, though they continued to focus on the environment. In developing party policy, they attempted to apply the values of environmental philosophy to all issues facing their countries, including foreign policy, defense, and social and economic policies.

The international environmental movement. By the late 1980s environmentalism had become a global as well as a national political force. Some environmental nongovernmental organizations (*e.g.,* Greenpeace, Friends of the Earth, and the World Wildlife Fund) established a significant international presence, with offices throughout the world and centralized international headquarters.

Through its international activism, the environmental movement has influenced the agenda of international politics. Since the 1970s the variety of multilateral environmental agreements has increased to cover most aspects of environmental protection as well as many practices with environmental consequences, such as the trade in endangered species, the management of hazardous waste, especially nuclear waste, and armed conflict. The changing nature of public debate on the environment was reflected also in the organization of the 1992 United Nations Conference on Environment and Development (the Earth Summit) in Rio de Janeiro, Brazil, which was attended by some 180 countries and various business groups, nongovernmental organizations, and the media.

In the 21st century, the environmental movement has combined the traditional concerns of conservation, preservation, and pollution with more contemporary concerns with the environmental consequences of economic practices as diverse as tourism, trade, financial investment, and the conduct of war. Environmentalists are likely to intensify the trends of the late 20th century, during which some environmental groups increasingly worked in coalition not just with other emancipatory organizations, such as human rights and indigenous-peoples groups, but also with corporations and other businesses. (L.M.E.)

Environmental law

Environmental law comprises the principles, policies, directives, and regulations enacted and enforced by local, national, or international entities to regulate human treatment of the nonhuman world.

HISTORICAL DEVELOPMENT

Throughout history, national governments have passed laws to protect human health from environmental contamination. In about 80 AD the Senate of Rome passed legislation to protect the city's supply of clean water for drinking and bathing. In the 14th century England prohibited both the burning of coal in London and the disposal of waste into waterways. In 1681 the Quaker leader of the English colony of Pennsylvania, William Penn, ordered that one acre of forest be preserved for every five acres cleared for settlement, and, in the following century, Benjamin Franklin led various campaigns to curtail the dumping of waste. In the 19th century, during the Industrial Revolution, the British government passed regulations to reduce the deleterious effects of coal burning and chemical manufacture on public health and the environment.

Prior to the 20th century, there were few international environmental agreements. The accords that were reached focused primarily on boundary waters, navigation, and fishing rights along shared waterways and ignored ecological issues. In the early 20th century, conventions to protect commercially valuable species were reached, including the Convention for the Protection of Birds Useful to Agriculture (1902), signed by 12 European governments; the Convention for the Preservation and Protection of Fur Seals (1911), concluded by the United States, Japan, Russia, and the United Kingdom; and the Convention for the Protection of Migratory Birds (1916), adopted by the United States and the United Kingdom (on behalf of Canada) and later extended to Mexico in 1936. In the 1930s, Belgium, Egypt, Italy, Portugal, South Africa, the Sudan, and the United Kingdom adopted the Convention Relative to the Preservation of Fauna and Flora in their Natural State, which committed them to preserve natural fauna and flora in Africa by means of national parks and reserves.

Beginning in the 1960s environmentalism became an important political and intellectual movement in the West. In subsequent decades the U.S. government passed an extraordinary number of environmental laws—including acts addressing solid-waste disposal, air and water pollution, and the protection of endangered species—and created an Environmental Protection Agency (EPA) to monitor compliance with them. These new environmental laws dramatically increased the national government's role in an area previously left primarily to state and local regulation. The EPA

In Japan, rapid reindustrialization after World War II was accompanied by the indiscriminate release of industrial chemicals into the human food chain in certain areas. By the early 1960s the Japanese government had begun to consider a comprehensive pollution-control policy, and in 1967 Japan enacted the world's first such overarching law, the Basic Law for Environmental Pollution Control.

In 1971, 34 countries adopted the Convention on Wetlands of International Importance Especially as Waterfowl Habitat, known as the Ramsar Convention for the city in Iran in which it was signed. The agreement, which entered into force in 1975, now has nearly 100 parties. It required all countries to designate at least one protected wetland area, and it recognized the important role of wetlands in maintaining the ecological equilibrium.

Following the United Nations Conference on the Human Environment, held in Stockholm in 1972, the UN established the United Nations Environment Programme (UNEP) as the world's principal international environmental organization. Although UNEP oversees many modern-day agreements, it has little power to impose or enforce sanctions on noncomplying parties. Nevertheless, a series of important conventions arose directly from the conference, including the London Convention on the Prevention of Pollution by Dumping of Wastes or Other Matter (1972) and the Convention on International Trade in Endangered Species (1973).

Until the Stockholm conference, European countries generally had been slow to enact environmental legislation—though there had been some exceptions, such as the passage of the conservationist Countryside Act in the United Kingdom in 1968. In October 1972, only a few months after the UN conference, the leaders of the European Com-

munity (EC) declared that the goal of economic expansion should be balanced with the need to protect the environment. In the following year the European Commission, the EC's executive branch, produced its first Environmental Action Programme, and since that time European countries have been at the forefront of environmental policy making. In Germany, for example, public attitudes toward environmental protection changed dramatically in the early 1980s, when it became known that many German forests were being destroyed by acid rain. The German Green Party campaigned successfully for stricter environmental regulations, and by the end of the 20th century it had joined a coalition government and was responsible for developing and implementing Germany's extensive environmental policies.

The Chernobyl accident

During the 1980s the "transboundary effects" of environmental pollution spurred negotiations on several international environmental conventions. The effects of the 1986 accident at the Soviet nuclear power plant at Chernobyl were especially significant. European countries in the pollution's downwind path were forced to adopt measures to restrict their populations' consumption of water, milk, meat, and vegetables. In Austria traces of radiation were found in cow's milk as well as in human breast milk. As a direct result of the Chernobyl disaster, two international agreements—the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency, both adopted in 1986—were rapidly drafted to ensure notification and assistance in the event of a nuclear accident. In 1994 the Convention on Nuclear Safety established incentives for countries to adopt basic standards for the safe operation of land-based nuclear power plants.

There are often conflicting data about the environmental impact of human activities, and scientific uncertainty often has complicated the drafting and implementation of environmental laws and regulations, particularly for international conferences attempting to develop universal standards. Consequently, such laws and regulations usually are designed to be flexible enough to accommodate changes in scientific understanding and technological capacity. The Vienna Convention for the Protection of the Ozone Layer (1985), for example, did not specify the measures that signatory states were required to adopt to protect human health and the environment from the effects of ozone depletion, nor did it mention any of the substances that were thought to damage the ozone layer. Similarly, the Framework Convention on Climate Change, or Global Warming Convention, adopted at the 1992 Earth Summit, did not set binding targets for reducing the emission of the "greenhouse" gases thought to cause global warming.

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Belarusian soldiers check the radiation level of tomatoes grown 30 miles (50 kilometres) from the Chernobyl nuclear plant, September 7, 2002. Radiation levels in that region of Ukraine were 500–600 microroentgen per hour, 20–30 times the norm.

In 1995 the Intergovernmental Panel on Climate Change concluded that "the balance of evidence suggests a discernible human influence on global climate." Although cited by environmentalists as final proof of the reality of global warming, some critics claimed that the report relied on insufficient data and used unrealistic models of climate change. Two years later in Kyōto, Japan, a conference of signatories to the Framework Convention adopted the Kyōto Protocol, which featured binding emission targets for developed countries. The protocol authorized developed countries to engage in emissions trading in order to meet their emissions targets. Its market mechanisms included the sale of "emission reduction units," which are earned when a developed country reduces its emissions below its commitment level, to developed countries that have failed to achieve their emission targets. Developed countries could earn additional emission reduction units by financing energy-efficient projects (*e.g.,* clean-development mechanisms) in developing countries. Since its adoption, the protocol has encountered opposition from some countries, particularly the United States, which announced in 2001 that it would not ratify the agreement.

The Kyōto Protocol

LEVELS OF ENVIRONMENTAL LAW

Environmental law exists at many levels and is only partly constituted by international declarations, conventions, and treaties. The bulk of environmental law is statutory—*i.e.,* encompassed in the enactments of legislative bodies—and regulatory—*i.e.,* generated by agencies charged by governments with protection of the environment.

In addition, many countries have included some right to environmental quality in their national constitutions. Since 1994, for example, environmental protection has been enshrined in the German Grundgesetz ("Basic Law"), which states that the government must protect for "future generations the natural foundations of life." Similarly, the Chinese constitution declares that the state "ensures the rational use of natural resources and protects rare animals and plants"; and the South African constitution recognizes a right to "an environment that is not harmful to health or well-being; and to have the environment protected, for the benefit of present and future generations."

Much environmental law also is embodied in the decisions of international, national, and local courts. Some of it is manifested in arbitrated decisions, such as the Trail Smelter arbitration (1941), which enjoined the operation of a smelter located in British Columbia, Canada, near the international border with the U.S. state of Washington and held that "no State has the right to use or permit the use of its territory in such a manner as to cause injury by fumes in or to the territory of another or the properties or persons therein." Some environmental law also appears in the decisions of national courts. For example, in *Scenic Hudson Preservation Conference* v. *Federal Power Commission* (1965), a U.S. federal appeals court voided a license granted by the Federal Power Commission for the construction of an environmentally damaging pumped-storage hydroelectric plant (*i.e.,* a plant that would pump water from a lower to an upper reservoir) in an area of stunning natural beauty. Significant local decisions included *National Audubon Society* v. *Superior Court* (1976), in which the California Supreme Court dramatically limited the ability of the city of Los Angeles to divert water that might otherwise fill Mono Lake in California's eastern desert.

TYPES OF ENVIRONMENTAL LAW

Command-and-control legislation. Most environmental law falls into a general category of laws known as "command and control." Such laws typically involve three elements: (1) identification of a type of environmentally

harmful activity, (2) imposition of specific conditions or standards on that activity, and (3) prohibition of forms of the activity that fail to comply with the imposed conditions or standards. The U.S. Federal Water Pollution Control Act (1972), for example, regulates "discharges" of "pollutants" into "navigable waters of the United States." All three terms are defined in the statute and agency regulations and together identify the type of environmentally harmful activity subject to regulation. Almost all environmental laws prohibit regulated activities that do not comply with stated conditions or standards. Many make a "knowing" violation of such standards a crime.

The most obvious forms of regulated activity involve actual discharges of pollutants into the environment. Environmental laws also regulate activities that entail a significant risk of discharging harmful pollutants (*e.g.,* the transportation of hazardous waste). For actual discharges, specific thresholds of allowable pollution are prescribed; for activities that create a risk of discharge, management practices to reduce the risk are established.

Environmental-quality and discharge standards

The standards imposed on actual discharges generally come in two forms: (1) environmental-quality, or ambient, standards, which fix the maximum amount of the regulated pollutant or pollutants tolerated in the receiving body of air or water; and (2) emission, or discharge, standards, which regulate the amount of the pollutant or pollutants that any "source" may discharge into the environment. Most comprehensive environmental laws impose both environmental-quality and discharge standards in coordination to achieve a stated environmental-quality goal. Such goals can be either numerical or narrative. Numerical targets set a specific allowable quantity of a pollutant (*e.g.,* 10 micrograms of carbon monoxide per cubic metre of air measured over an eight-hour period). Narrative standards require that the receiving body of air or water be suitable for a specific use (*e.g.,* swimming).

The management practices prescribed for activities that create a risk of discharge are diverse and context-specific. The U.S. Resource Conservation and Recovery Act (1991), for example, requires drip pads for containers in which hazardous waste is accumulated or stored, and the U.S. Oil Pollution Act (1990) mandates that all oil tankers of a certain size and age operating in U.S. waters be double-hulled.

Another type of activity regulated by command-and-control legislation is environmentally harmful trade. Among the most developed regulations are those on trade in wildlife. The Convention on International Trade in Endangered Species (CITES, 1973) authorizes signatories to the convention to designate species "threatened with extinction which are or may be affected by trade." Once a plant or animal species has been designated as endangered, countries generally are bound to prohibit import or export of that species except in specific limited circumstances. In 1989, the listing of the African elephant as a protected species effectively prohibited most trade in African ivory, which was subsequently banned by Kenya and the EC. By this time the United States already had banned trade in African ivory, listing the African elephant as a threatened species under its Federal Endangered Species Act (1978). Despite these measures, some countries either failed to prohibit ivory imports or refused to prohibit ivory exports, and elephants continued to face danger from poachers and smugglers.

Environmental assessment mandates. Environmental assessment mandates are another significant form of environmental law. Such mandates generally perform three functions: (1) identification of a level or threshold of potential environmental impact at which a contemplated action is significant enough to require the preparation of an assessment; (2) establishment of specific goals for the assessment mandated; and (3) setting of requirements to ensure that the assessment will be considered in determining whether to proceed with the action as originally contemplated or to pursue an alternative action. Unlike command-and-control regulations, which may directly limit discharges into the environment, mandated environmental assessments protect the environment indirectly by increasing the quantity and quality of publicly available information on the environmental consequences of contemplated actions. This information potentially improves the decision making of government officials and increases the public's involvement in the creation of environmental policy.

The U.S. National Environmental Policy Act (1969) requires an environmental-impact statement for any "major federal action significantly affecting the quality of the human environment." The statement must analyze the environmental impact of the proposed action and consider a range of alternatives, including a so-called "no-action alternative." The statute and regulations imposed by the Council on Environmental Quality, which was established under the 1969 act to coordinate federal environmental initiatives, require federal agencies to wait until environmental-impact statements have been completed before taking actions that would preclude alternatives. Similarly, the European Union (EU) requires an environmental-impact assessment for two types of projects. So-called "annex-I Projects" (*e.g.,* oil refineries, toxic-waste landfills, and thermal power stations with heat output of 300 or more megawatts) are generally subject to the requirement, and "annex-II Projects" (*e.g.,* activities in chemical, food, textile, leather, wood, and paper industries) are subject to an assessment only where "member states consider that their characteristics so require."

Economic incentives. The use of economic instruments to create incentives for environmental protection is a popular form of environmental law. Such incentives include pollution taxes, subsidies for clean technologies and practices, and the creation of markets in either environmental protection or pollution. Denmark, The Netherlands, and Sweden, for example, impose taxes on carbon-dioxide emissions, and the EU has debated whether to implement such a tax at the supranational level to combat climate change. In 1980, prompted in part by the national concern inspired by industrial pollution in the Love Canal neighbourhood in New York, the U.S. government created a federal "superfund" that used general revenues and revenue from taxes on petrochemical feedstocks, crude oil, general corporate income to finance the cleanup of more than one thousand sites polluted by hazardous substances.

Tradable-allowance schemes

By the 1990s tradable-allowance schemes, which permit companies to buy and sell "pollution credits," or legal rights to produce specified amounts of pollution, had been implemented in the United States. The most comprehensive and complex such program, created as part of the 1990 Clean Air Act, was designed to reduce overall sulfur-dioxide emissions by fossil-fuel-fired power plants. According to proponents, the program would provide financial rewards to cleaner plants, which could sell their unneeded credits on the market, and allow dirtier plants to stay in business while they converted to cleaner technologies.

Set-aside schemes. A final method of environmental protection is the setting aside of lands and waters in their natural state. In the United States, the vast majority of the land owned by the federal government (about one-third of the total land area of the country) can be developed only with the approval of a federal agency. Europe has an extensive network of national parks and preserves on both public and private land, and there are large national parks in southern and eastern Africa.

Many areas of law can be characterized as both set-aside and regulatory. International efforts to preserve wetlands have focused on setting aside areas of ecological value, including wetlands, and on regulating their use. The Ramsar Convention provides that wetlands are a significant "economic, cultural, scientific and recreational" resource, and a section of the Clean Water Act, the primary U.S. law for the protection of wetlands, contains a prohibition against unpermitted discharges of "dredge and fill material" into any "waters of the United States."

PRINCIPLES OF ENVIRONMENTAL LAW

The design and application of modern environmental law have been shaped by principles outlined in publications such as *Our Common Future* (1987), published by the World Commission on Environment and Development, and the Earth Summit's Rio Declaration (1992).

The precautionary principle. As discussed above, environmental law regularly operates in areas complicated by

The problem of scientific uncertainty

high levels of scientific uncertainty. In the case of many activities that entail some change to the environment, it is impossible to determine precisely what effects the activity will have on the quality of the environment or on human health. It is generally impossible to know, for example, whether a certain level of air pollution will result in an increase in mortality from respiratory disease, whether a certain level of water pollution will reduce a healthy fish population, or whether oil development in an environmentally sensitive area will significantly disturb the native wildlife. The precautionary principle requires that, if there is a strong suspicion that a certain activity may have environmentally harmful consequences, it is better to control that activity now rather than to wait for incontrovertible scientific evidence. This principle is expressed in the Rio Declaration, which stipulates that, where there are "threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." In the United States the precautionary principle was incorporated into the design of habitat-conservation plans required under the aegis of the Endangered Species Act. In 1989 the EC invoked the precautionary principle when it banned the importation of U.S. hormone-fed beef, and in 2000 the organization adopted the principle as a "full-fledged and general principle of international law."

The prevention principle. Although much environmental legislation is drafted in response to catastrophes, preventing environmental harm is cheaper, easier, and less environmentally dangerous than reacting to environmental harm that already has taken place. The prevention principle is the fundamental notion behind laws regulating the generation, transportation, treatment, storage, and disposal of hazardous waste and laws regulating the use of pesticides. The principle was the foundation of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1989), which sought to minimize the production of hazardous waste and to combat illegal dumping. The prevention principle also was an important element of the EC's Third Environmental Action Programme, which was adopted in 1983.

The "polluter-pays" principle. Since the early 1970s the "polluter-pays" principle has been a dominant concept in environmental law. Many economists claim that much environmental harm is caused by producers who "externalize" the costs of their activities. For example, factories that emit unfiltered exhaust into the atmosphere or discharge untreated chemicals into a river pay little to dispose of their waste. Instead, the cost of waste disposal, in the form of pollution, is borne by the entire community. Accordingly, the purpose of many environmental regulations is to force polluters to bear the real costs of their pollution, though such costs often are difficult to calculate precisely. In theory, such measures encourage producers of pollution to make cleaner products or to use cleaner technologies. The polluter-pays principle underlies U.S. laws requiring the cleanup of releases of hazardous substances, including oil. One such law, the Oil Pollution Act (1990), was passed in reaction to the spillage of some 11 million gallons (42 million litres) of oil into Prince William Sound in Alaska in 1989. The polluter-pays principle also guides the policies of the EU and other governments throughout the world. A 1991 ordinance in Germany, for example, held businesses responsible for the costs of recycling or disposing of their products' packaging, up to the end of the product's life cycle; however, the German Federal Consti- tutional Court struck down the regulation as unconstitutional.

The integration principle. Environmental protection requires that due consideration be given to the potential consequences of environmentally fateful decisions. Various jurisdictions (*e.g.*, the United States and the EU) and business organizations (*e.g.*, the U.S. Chamber of Commerce) have integrated environmental considerations into their decision-making processes, through both environmental-impact assessment mandates and other provisions.

The public-participation principle. Decisions about environmental protection often formally integrate the views of the public. Generally, government decisions to set environmental standards for specific types of pollution, to permit significant environmentally damaging activities, or to preserve significant resources are made only after the impending decision has been publicly announced and the public has been given the opportunity to influence the decision through written comments or hearings. In many countries, citizens may challenge government decisions affecting the environment in court or before administrative bodies. These citizen lawsuits have become an important component of environmental decision making at both the national and the international level.

Public participation in environmental decision making has been facilitated in Europe and North America by laws that mandate public access to government information on the environment. Similar measures at the international level include the Rio Declaration and the 1998 Århus Convention, which committed the 40 European signatory states to increase the environmental information available to the public and to enhance the public's ability to participate in government decisions that affect the environment.

Sustainable development. Sustainable development is an approach to economic planning that attempts to foster economic growth while preserving the quality of the environment for future generations. Despite its enormous popularity in the last two decades of the 20th century, the concept proved difficult to apply in many cases, primarily because the results of long-term sustainability analyses depend on the particular resources focused upon. For example, a forest that will provide a sustained yield of timber in perpetuity may not support native bird populations, and a mineral deposit that will eventually be exhausted may nevertheless support more or less sustainable communities. Sustainability was the focus of the 1992 Earth Summit and later was central to a multitude of environmental studies.

Ecotourism

One of the most important areas of the law of sustainable development is ecotourism. Although tourism poses the threat of environmental harm from pollution and the overuse of natural resources, it also can create economic incentives for the preservation of the environment in developing countries and increase awareness of unique and fragile ecosystems throughout the world. In 1995 the World Conference on Sustainable Tourism, held on the island of Lanzarote in the Canary Islands, adopted a charter that encouraged the development of laws that would promote the dual goals of economic development through tourism and protection of the environment. Two years later, in the Malé Declaration on Sustainable Tourism, 27 Asia-Pacific countries pledged themselves to a set of principles that included fostering awareness of environmental ethics in tourism, reducing waste, promoting natural and cultural diversity, and supporting local economies and local-community involvement.

CURRENT TRENDS

Although numerous international environmental treaties have been concluded, effective agreements remain difficult to achieve for a variety of reasons. Because environmental problems ignore political boundaries, they can be adequately addressed only with the cooperation of numerous governments, among which there may be serious disagreements on environmental policy. Furthermore, because the measures necessary to address environmental problems typically result in social and economic hardships in the countries that adopt them, many countries, particularly in the developing world, have been reluctant to enter into environmental treaties. Since the 1970s a growing number of environmental treaties have incorporated provisions designed to encourage their adoption by developing countries. Such measures include financial cooperation, technology transfer, and differential implementation schedules and obligations.

The greatest challenge to the effectiveness of environmental treaties is compliance. Although treaties can attempt to enforce compliance through mechanisms such as sanctions, such measures usually are of limited usefulness, in part because countries in compliance with a treaty may be unwilling or unable to impose the sanctions the treaty calls for. In general, the threat of sanctions is less important to most countries than the possibility that by violating their international obligations they risk losing their good

standing in the international community. Enforcement mechanisms other than sanctions have been difficult to establish, usually because they would require countries to cede significant aspects of their national sovereignty to foreign or international organizations. In most agreements, therefore, enforcement is treated as a domestic issue, an approach that effectively allows each country to define compliance in whatever way best serves its interest.

Many areas of international environmental law remain underdeveloped. Although international agreements have helped to make the laws and regulations applying to some types of environmentally harmful activity more or less consistent in different countries, those applying to other types can differ in dramatic ways. Because in most cases the damage caused by such activities cannot be contained within national boundaries, the lack of consistency in the law has led to situations in which activities that are legal in some countries result in illegal or otherwise unacceptable levels of environmental damage in neighbouring countries.

NAFTA

This problem became particularly acute with the adoption of free-trade agreements beginning in the early 1990s. The North American Free Trade Agreement (NAFTA), for example, resulted in the creation of large numbers of maquiladoras—factories jointly owned by American and Mexican corporations and operated in Mexico—inside a 60-mile- (100-km) wide free-trade zone along the U.S.-Mexican border. Because Mexico's government lacked both the resources and the political will to enforce the country's environmental laws, the maquiladoras were able to pollute surrounding areas with relative impunity, often dumping hazardous wastes on the ground or directly into waterways, where they were carried into U.S. territory. Prior to NAFTA's adoption in 1992, the prospect of problems such as these led negotiators to append a so-called "side agreement" to the treaty, which pledged environmental cooperation between the signatory states. (F.C./C.I.C.-M.)

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Epistemology

Epistemology is the philosophical discipline that studies the nature, origin, and limits of human knowledge. The term is derived from the Greek *epistēmē* ("knowledge") and *logos* ("reason"), and accordingly the field is sometimes referred to as the theory of knowledge. Epistemology has a long history, from the ancient Greeks to the present. Along with metaphysics, logic, and ethics, it is one of the four main branches of philosophy, and nearly every great philosopher has contributed to it.

For coverage of related topics in the *Macropædia* and the *Micropædia*, see the *Propædia*, sections 10/51, 10/52, and 10/53, and the *Index*.

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The nature of epistemology

EPISTEMOLOGY AS A DISCIPLINE

Why should there be a discipline such as epistemology? Aristotle (384–322 BC) provided the answer when he said that philosophy begins in a kind of wonder or puzzlement. Nearly all human beings wish to comprehend the world they live in, and many construct theories to help make sense of it. Because many aspects of the world defy easy explanation, however, most people are likely to cease their efforts at some point and to content themselves with whatever degree of understanding they have achieved.

Unlike most people, philosophers are captivated—some would say obsessed—by the idea of understanding the world in the most general terms possible. Accordingly, they attempt to construct theories that are synoptic, descriptively accurate, explanatorily powerful, and in all other respects rationally defensible. In doing so, they carry the process of inquiry further than other people tend to do, and this is what is meant by saying that they develop a philosophy about these matters.

Like most people, epistemologists often begin their speculations with the assumption that they have a great deal of knowledge. As they reflect upon what they presumably know, however, they discover that it is much less secure than they realized, and indeed they come to think that many of what had been their firmest beliefs are dubious or even false. Such doubts arise from certain anomalies in our experience of the world. Although several of these anom-

alies are discussed below in the section on the history of epistemology, two in particular will be described in detail here in order to illustrate how they call into question our common claims to knowledge about the world.

TWO EPISTEMOLOGICAL PROBLEMS

Visual anomalies

Knowledge of the external world. Most people have noticed that vision can play tricks. A straight stick submerged in water looks bent, though it is not; railroad tracks seem to converge in the distance, but they do not; the wheels on a forward-moving wagon appear to turn backward, but they do not. Each of these phenomena is misleading in some way. Anyone who believes that the stick is bent, that the railroad tracks converge, and so on is mistaken about how the world really is.

Although these anomalies may seem simple and unproblematic at first, deeper consideration of them shows that just the opposite is true. How does one know that the stick is not really bent and that the tracks do not really converge? Suppose one says that one knows that the stick is not really bent because, when it is removed from the water, one can see that it is straight. But does seeing a straight stick out of water provide a good reason for thinking that, when it is in water, it is not bent? Suppose one says that the tracks do not really converge because the train passes over them at the point where they seem to converge. But how does one know that the wheels on the train do not converge at that point also? What justifies our preferring some of these beliefs to others, especially when all of them are based upon what is seen? What one sees is that the stick in water is bent and the stick out of water is straight. Why then is the stick declared really to be straight? Why in effect is priority given to one perception over another?

One possible answer is to say that vision is not sufficient to give knowledge of how things are. Vision needs to be "corrected" with information derived from the other senses. Suppose then that a person asserts that his reason for believing that the stick in water is straight is that, when the stick is in water, he can feel with his hands that it is straight. But what justifies him in believing that his sense of touch is more reliable than his vision? After all, touch gives rise to misperceptions just as vision does. For example, if a person chills one hand and warms the other and then puts both in a tub of lukewarm water, the water will feel warm to the cold hand and cold to the warm hand. Thus, the difficulty cannot be resolved by appealing to input from the other senses.

Reason as a corrective perception

Another possible response would begin by granting that none of the senses is guaranteed to present things as they really are. The belief that the stick is really straight, therefore, must be justified on the basis of some other form of awareness, perhaps reason. But why should reason be accepted as infallible? It is often used imperfectly, as when one forgets, miscalculates, or jumps to conclusions. Moreover, why should one trust reason if its conclusions run counter to those derived from sensation, considering that sense experience is obviously the basis of much of what is known about the world?

Clearly there is a network of difficulties here, and one will have to think hard in order to arrive at a compelling defense of the apparently simple claim that the stick is truly straight. A person who accepts this challenge will, in effect, be addressing the larger philosophical problem of our knowledge of the external world. That problem consists of two issues: how one can know whether there is a reality that exists independently of sense experience, given that sense experience is ultimately the only evidence one has for the existence of anything, and how one can know what anything is really like, given that different kinds of sensory evidence often conflict with each other.

The other-minds problem. Suppose a surgeon tells a patient who is about to undergo a knee operation that when he wakes up he will feel a sharp pain. When the patient wakes up, the surgeon hears him groaning and sees him contorting his face in certain ways. Although we are naturally inclined to say that the surgeon knows what the patient is feeling, there is a sense in which he does not know, because he is not feeling that kind of pain himself. Unless he has undergone such an operation in the past, he cannot know what his patient feels. Indeed, the situation is more complicated than this, for even if the surgeon has undergone such an operation, he cannot know that what he felt after his operation is the same sort of sensation as what his patient is feeling now. Because each person's sensations are in a sense "private," for all the surgeon knows, what he understands as pain and what the patient understands as pain could be very different. (Similar remarks apply to our use of colour terms. For all a person knows, the colour sensation he associates with "green" could be very different from the sensations other people associate with that term. This possibility is known as the problem of the inverted spectrum.)

It follows from this analysis that each human being is inevitably and even in principle prevented from having knowledge of the minds of other human beings. Despite the widely held conviction that in principle there is nothing in the world of fact that cannot be known through scientific investigation, the other-minds problem shows to the contrary that an entire domain of human experience is resistant to any sort of external inquiry. Thus, there can never be a science of the human mind.

Issues in epistemology

THE NATURE OF KNOWLEDGE

As indicated above, one of the basic questions of epistemology concerns the nature of knowledge. Philosophers normally treat this question as a conceptual one—*i.e.*, as an inquiry into a certain concept or idea. The question raises a perplexing methodological issue: namely, how does one go about investigating concepts?

It is frequently assumed, though the matter is controversial, that one can determine what knowledge is by considering what the word "knowledge" means. Although concepts are not the same as words, words—*i.e.*, languages—are the medium in which concepts are displayed. Hence, examination of the ways in which words are used can yield insight into the nature of the concepts associated with them.

Knowing "how" and knowing "that"

An investigation of the concept of knowledge, then, would begin by studying uses of "knowledge" and cognate expressions in everyday language. Expressions such as "know him," "know that," "know how," "know where," "know why," and "know whether," for example, have been explored in detail, especially since the beginning of the 20th century. As Gilbert Ryle (1900–76) has pointed out, there are important differences between "know how" and "know that." The former expression is normally used to refer to a kind of skill or ability, such as knowing how to swim. One can have such knowledge without being able to explain to other people what it is that one knows in such a case—that is, without being able to convey the same skill. The expression "know what" is similar to "know how" in this respect, insofar as one can know what a clarinet sounds like without being able to say what one knows—at least not succinctly. "Know that," in contrast, seems to denote the possession of specific pieces of information, and the person who has knowledge of this sort generally can convey it to others. Knowing that the Concordat of Worms was signed in the year 1122 is an example of this sort of knowledge. Ryle argued that, given these differences, some cases of knowing how cannot be reduced to cases of knowing that, and, accordingly, the kinds of knowledge expressed by these phrases are independent of each other.

For the most part, epistemology from the ancient Greeks to the present has focused on "knowing that." This sort of knowledge, often referred to as propositional knowledge, raises a number of peculiar epistemological problems, among which is the much-debated issue of what kind of thing one knows when one knows that something is the case. In other words, in sentences of the form "A knows that p"—where "A" is the name of some person and "p" is a sentential clause, such as "snow is white"—what sort of entity does "p" refer to? The list of candidates has included beliefs, propositions, statements, sentences, and utterances of sentences. Although the arguments for and against the various candidates are beyond the scope of this article, two points should be noted here: first, the issue is closely

related to the problem of universals—*i.e.*, the problem of whether qualities or properties, such as redness, are abstract objects, mental concepts, or simply names. Second, it is agreed by all sides that one cannot have "knowledge that" of that which is not true. A necessary condition of "A knows that *p*," therefore, is *p*.

FIVE DISTINCTIONS

Mental and nonmental conceptions of knowledge. Some philosophers have held that knowledge is a state of mind—*i.e.*, a special kind of awareness of things. According to Plato (428/27–348/47 BC), for example, knowing is a mental state akin to, but different from, believing. Contemporary versions of this theory assert that knowing is one member of a group of mental states that can be arranged in a series according to increasing certitude. At one end of the series would be guessing and conjecturing, which possess the least amount of certitude; in the middle would be thinking, believing, and feeling sure; and at the end would be knowing, the most certain of all these states. Knowledge, in all views of this type, is a form of consciousness, and accordingly it is common for proponents of such views to hold that, if A knows that *p*, A must be conscious of what he knows. That is, if A knows that *p*, A knows that he knows that *p*.

Knowledge as a form of consciousness

In the 20th century, many philosophers rejected the notion that knowledge is a mental state. Ludwig Wittgenstein (1889–1951), for example, said in *On Certainty*, published posthumously in 1969, that "'Knowledge' and certainty belong to different categories. They are not two mental states like, say surmising and being sure." Philosophers who deny that knowledge is a mental state typically point out that it is characteristic of mental states like doubting, being in pain, and having an opinion that a person who is in such a state is aware that he is in it. They then observe that it is possible to know that something is the case without being aware that one knows it. A good example is found in Plato's *Meno*, where Socrates (*c.* 470–399 BC) elicits from a slave boy geometrical knowledge that the boy was not aware he had. They conclude that it is a mistake to assimilate cases of knowing to cases of doubting, being in pain, and the like.

But if knowing is not a mental state, what is it? Some philosophers have held that knowing cannot be described as a single thing, such as a state of consciousness. Instead, they claim that one can ascribe knowledge to someone, or to oneself, only when certain complex conditions are satisfied, among them certain behavioral conditions. For example, if a person always gives the right answers to questions about a certain topic under test conditions, one would be entitled, on this view, to say that he has knowledge of that topic. Because knowing is tied to the capacity to behave in certain ways, knowledge is not a mental state, though mental states may be involved in the exercise of the capacity that constitutes knowledge.

Warranted assertion of knowledge claims

An example of such a view was advanced by J.L. Austin (1911–60) in his 1946 paper "Other Minds." Austin claimed that, when one says "I know," one is not describing a mental state; in fact, one is not "describing" anything at all. Instead, one is indicating that one is in a position to assert that such and such is the case (one has the proper credentials and reasons) in circumstances where it is necessary to resolve a doubt. When these conditions are satisfied—when one is, in fact, in a position to assert that such and such is the case—one can correctly be said to know.

Occurrent and dispositional knowledge. A distinction closely related to the previous one is that between "occurrent" and "dispositional" knowledge. Occurrent knowledge is knowledge of which one is currently aware. If one is working on a problem and suddenly sees the solution, for example, one can be said to have occurrent knowledge of it, because "seeing" the solution involves being aware of or attending to it. In contrast, dispositional knowledge, as the term suggests, is a disposition, or a propensity, to behave in certain ways in certain conditions. Although Smith may not now be thinking of his home address, he certainly knows it in the sense that, if one were to ask him what it is, he could provide it. Thus, one can have knowledge of things of which one is not aware at a given moment.

A priori and a posteriori knowledge. Since at least the 17th century, a sharp distinction has been drawn between a priori knowledge and a posteriori knowledge. The distinction plays an especially important role in the work of David Hume (1711–76) and Immanuel Kant (1724–1804).

The distinction is easily illustrated by means of examples. Assume that the sentence "All Model-T Fords are black" is true and compare it to the true sentence "All husbands are married." How would one come to know that these sentences are true? In the case of the second sentence, the answer is that one knows that it is true by understanding the meanings of the words it contains. Because "husband" means "married male," it is true by definition that all husbands are married. This kind of knowledge is a priori in the sense that one need not engage in any factual or empirical inquiry in order to obtain it. In contrast, just such an investigation is necessary in order to know whether the first sentence is true. Unlike the second sentence, simply understanding the words is not enough. Knowledge of this kind is a posteriori in the sense that it can be obtained only through certain kinds of experience.

The differences between sentences that express a priori knowledge and those that express a posteriori knowledge are sometimes described in terms of four additional distinctions: necessary versus contingent, analytic versus synthetic, tautological versus significant, and logical versus factual. These distinctions are normally spoken of as applying to "propositions," which may be thought of as the contents, or meanings, of sentences that can be either true or false. For example, the English sentence "Snow is white" and the German sentence "Schnee ist weiß" have the same meaning, which is the proposition "Snow is white."

Necessary and contingent propositions. A proposition is said to be necessary if it is true in all logically possible circumstances or conditions. "All husbands are married" is such a proposition. There are no possible or conceivable conditions in which this proposition is not true (on the assumption, of course, that the words "husband" and "married" are taken to mean what they ordinarily mean). In contrast, "All Model-T Fords are black" holds in some circumstances (those actually obtaining, which is why the proposition is true), but it is easy to imagine circumstances in which it would not be true. To say, therefore, that a proposition is contingent is to say that it is true in some but not in all possible circumstances. Many necessary propositions, such as "All husbands are married," are a priori—though it has been argued that some are not—and most contingent propositions are a posteriori.

Analytic and synthetic propositions. A proposition is said to be analytic if the meaning of the predicate term is contained in the meaning of the subject term. Thus, "All husbands are married" is analytic because part of the meaning of the term "husband" is being married. A proposition is said to be synthetic if this is not so. "All Model-T Fords are black" is synthetic, since "black" is not included in the meaning of "Model-T Ford." Some analytic propositions are a priori, and most synthetic propositions are a posteriori. These distinctions were used by Kant to ask one of the most important questions in the history of epistemology, namely, whether a priori synthetic judgments are possible (see below *Modern philosophy: Immanuel Kant*).

Tautological and significant propositions. A proposition is said to be tautological if its constituent terms repeat themselves or if they can be reduced to terms that do, so that the proposition is of the form "a = a" ("a is identical to a"). Such propositions convey no information about the world, and accordingly they are said to be trivial, or empty of cognitive import. A proposition is said to be significant if its constituent terms are such that the proposition does provide new information about the world.

The distinction between tautological and significant propositions figures importantly in the history of the philosophy of religion. In the so-called ontological argument for the existence of God, St. Anselm of Canterbury (1033/34–1109) attempted to derive the significant conclusion that God exists from the tautological premise that God is the only perfect being together with the premise that no being can be perfect unless it exists. As Hume and

The ontological argument

Kant pointed out, however, it is fallacious to derive a proposition with existential import from a tautology, and it is now generally agreed that, from a tautology alone, it is impossible to derive any significant proposition. Tautological propositions are generally a priori, necessary, and analytic, and significant propositions are generally a posteriori, contingent, and synthetic.

Logical and factual propositions. A logical proposition is any proposition that can be reduced by replacement of its constituent terms to a proposition expressing a logical truth—*e.g.,* to a proposition such as "If p and q, then p." The proposition "All husbands are married," for example, is logically equivalent to the proposition "If something is married and it is male, then it is married." In contrast, the semantic and syntactic features of factual propositions make it impossible to reduce them to logical truths. Logical propositions are often a priori, always necessary, and typically analytic. Factual propositions are generally a posteriori, contingent, and synthetic.

Description and justification. Throughout its history, epistemology has pursued two different sorts of task: description and justification. The two tasks of description and justification are not inconsistent, and indeed they are often closely connected in the writings of contemporary philosophers.

In its descriptive task, epistemology aims to depict accurately certain features of the world, including the contents of the human mind, and to determine what kinds of mental content, if any, ought to count as knowledge. An example of a descriptive epistemological system is the phenomenology of Edmund Husserl (1859–1938). Husserl's aim was to give an exact description of the phenomenon of intentionality, or the feature of conscious mental states by virtue of which they are always "about," or "directed toward," some object. In his posthumously published masterpiece *Philosophical Investigations* (1953), Wittgenstein states that "explanation must be replaced by description," and much of his later work was devoted to carrying out that task. Other examples of descriptive epistemology can be found in the work of G.E. Moore (1873–1958), H.H. Price (1899–1984), and Bertrand Russell (1872–1970), each of whom considered whether there are ways of apprehending the world that do not depend on any form of inference and, if so, what this apprehension consists of (see below *Contemporary philosophy: Perception and knowledge*). Closely related to this work were attempts by various philosophers, including Moritz Schlick (1882–1936), Otto Neurath (1882–1945), and A.J. Ayer (1910–89), to identify "protocol sentences"—*i.e.,* statements that describe what is immediately given in experience without inference.

The normative function of epistemology

Epistemology has a second justificatory, or normative, function. Philosophers concerned with this function ask themselves what kinds of belief (if any) can be rationally justified. The question has normative import since it asks, in effect, what one ought ideally to believe. The normative approach quickly takes one into the central domains of epistemology, raising questions such as: "Is knowledge identical with justified true belief?," "Is the difference between knowledge and belief merely a matter of probability?," and "What is justification?"

Knowledge and certainty. Philosophers have disagreed sharply about the complex relationship between the concepts of knowledge and certainty. Are they the same? If not, how do they differ? Is it possible for someone to know that p without being certain that p, or to be certain that p without knowing that p?

In his 1941 paper "Certainty," Moore observed that the word "certain" is commonly used in four main types of idiom: "I feel certain that," "I am certain that," "I know for certain that," and "It is certain that." He pointed out that there is at least one use of "I know for certain that p" and "It is certain that p" on which neither of these sentences can be true unless p is true. A sentence such as "I knew for certain that he would come but he didn't," for example, is self-contradictory, whereas "I felt certain he would come but he didn't" is not. On the basis of considerations like these, Moore contended that "a thing can't be certain unless it is known." It is this fact that distinguishes the concept of certainty from that of truth: a thing that nobody knows may well be true, but it cannot possibly be certain. Moore concludes that a necessary condition for the truth of "It is certain that p" is that somebody should know that p. Moore is therefore among the philosophers who answer in the negative the question of whether it is possible for someone to be certain that p without knowing that p.

Moore also argued that to say "A knows that p is true" cannot be a sufficient condition for "It is certain that p." If it were, it would follow that, in any case in which at least one person did know that p is true, it would always be false for anyone to say "It is not certain that p"; but clearly this is not so. If a person says that it is not certain that Smith is still alive, he is not thereby committing himself to the statement that nobody knows that Smith is still alive. Moore is thus among the philosophers who would answer in the affirmative the question of whether it is possible for a person to know that p without being certain that p.

The most radical position on these matters is the one taken by Wittgenstein in *On Certainty.* Wittgenstein holds that knowledge is radically different from certitude and that neither concept entails the other. It is thus possible to be in a state of knowledge without being certain and to be certain without having knowledge. For him, certainty is to be identified not with apprehension, or "seeing," but with a kind of acting. A proposition is certain, in other words, when its truth (and the truth of many related propositions) is presupposed in the various social activities of a community. As he says: "Giving grounds, justifying the evidence comes to an end—but the end is not certain propositions striking us immediately as true—*i.e.,* it is not a kind of *seeing* on our part; it is our acting which lies at the bottom of the language game."

Certainty as a kind of acting

THE ORIGINS OF KNOWLEDGE

Philosophers wish to know not only what knowledge is but also how it arises. This desire is motivated in part by the assumption that an investigation into the origins of knowledge can shed light on its nature. Accordingly, such investigations have been one of the major themes of epistemology since the time of the ancient Greeks.

Plato's *Republic* contains one of the earliest systematic arguments to show that sense experience cannot be a source of knowledge. The argument begins with the assertion that ordinary persons have a clear grasp of certain concepts—*e.g.,* the concept of equality. In other words, people know what it means to say that a and b are equal, no matter what a and b are. But where does such knowledge come from? Consider the claim that two pieces of wood are of equal length. A close visual inspection would show them to differ slightly, and the more detailed the inspection, the more disparity one would notice. It follows that visual experience cannot be the source of the concept of equality. Plato applies this line of reasoning to all five senses and concludes that such knowledge cannot originate in sense experience. As in the *Meno,* discussed above, Plato concludes that such knowledge is "recollected" by the soul from an earlier existence.

Innate and acquired knowledge. The problem of the origins of knowledge has engendered two historically important kinds of debate. One of them concerns the question of whether knowledge is innate—*i.e.,* present in the mind, in some sense, from birth—or acquired through experience. This matter has been important not only in philosophy but also, since the mid-20th century, in linguistics and psychology. The American linguist Noam Chomsky, for example, has argued that the ability of young (developmentally normal) children to acquire any human language on the basis of invariably incomplete and even incorrect data is proof of the existence of innate linguistic structures. In contrast, the experimental psychologist B.F. Skinner (1904–90), a leading figure in the movement known as behaviourism, tried to show that all knowledge, including linguistic knowledge, is the product of learning through environmental conditioning by means of processes of reinforcement and reward. There also have been a range of "compromise" theories, which claim that humans have both innate and acquired knowledge.

Knowledge of language

Rationalism and empiricism. The second debate related

to the problem of the origins of knowledge is that between rationalism and empiricism. According to rationalists, the ultimate source of human knowledge is the faculty of reason; according to empiricists, it is experience. Reason is generally assumed to be a unique faculty of the mind through which truths about reality may be grasped. Such a thesis is double-sided: it holds, on the one hand, that reality is in principle knowable and, on the other hand, that there is a human faculty (or set of faculties) capable of knowing it. One thus might define rationalism as the theory that there is an isomorphism between reason and reality that makes it possible for the former to apprehend the latter just as it is. Rationalists contend that, if such a correspondence were lacking, it would be impossible for human beings to understand the world.

Almost no philosopher has been a strict, thorough-going empiricist—*i.e.*, one who holds that literally all knowledge comes from experience. Even John Locke (1632–1704), considered the father of modern empiricism, thought that there is some knowledge that does not derive from experience, though he held that it was "trifling" and empty of content. Hume held similar views.

Empiricism thus generally acknowledges the existence of a priori knowledge but denies its significance. Accordingly, it is more accurately defined as the theory that all significant or factual propositions are known through experience. Even defined in this way, however, it contrasts significantly with rationalism. Rationalists hold that human beings have knowledge that is prior to experience and yet significant. Empiricists deny that this is possible.

The term experience is usually understood to refer to ordinary physical sensations—or in Hume's parlance, "impressions." For strict empiricists this definition has the implication that the human mind is passive—a "tabula rasa" that receives impressions and more or less records them as they are.

The conception of the mind as a tabula rasa posed serious challenges for empiricists. It raised the question, for example, of how one can have knowledge of entities, such as dragons, that cannot be found in experience. The response of classical empiricists such as Locke and Hume was to show that the complex concept of a dragon can be reduced to simple concepts (such as wings, the body of a snake, the head of a horse), all of which derive from impressions. On such a view the mind is still considered primarily passive, but it is conceded that it has the power to combine simple ideas into complex ones.

But there are further difficulties. The empiricist must explain how abstract ideas, such as the concept of a perfect triangle, can be reduced to elements apprehended by the senses when no perfect triangles are found in nature. He must also give an account of how general concepts are possible. It is obvious that one does not experience "mankind" through the senses; yet such concepts are meaningful, and propositions containing them are known to be true. The same difficulty applies to colour concepts. Some empiricists have argued that one arrives at the concept of red, for example, by mentally abstracting from one's experience of individual red items. The difficulty with this suggestion is that one cannot know what to count as an experience of red unless one already has a concept of red in mind. If it is replied that the concept of red and others like it are acquired when we are taught the word red in childhood, a similar difficulty arises. The teaching process, according to the empiricist, consists of pointing to a red object and telling the child "This is red." This process is repeated a number of times until the child forms the concept of red by abstracting from the series of examples he is shown. But these examples are necessarily very limited: they do not include even a fraction of the shades of red the child might ever see. Consequently, it is possible for the child to abstract or generalize from them in a variety of different ways, only some of which would correspond to the way the community of adult language users happens to apply the term red. How then does the child know which abstraction is the "right" one to draw from the examples? According to the rationalist, the only way to account for the child's selection of the correct concept is to suppose that at least part of it is innate.

Challenges to empiricism

SKEPTICISM

Many philosophers, as well as many people studying philosophy for the first time, have been struck by the seemingly indecisive nature of philosophical argumentation. For every argument there seems to be a counterargument, and for every position a counterposition. To a considerable extent, skepticism is born of such reflection. The school of Academic Skepticism contended that all arguments are equally bad and, accordingly, that nothing can be proved. The contemporary American philosopher Benson Mates, who claims to be a modern representative of this tradition, has argued that all philosophical arguments are equally good.

Ironically, skepticism itself is a kind of philosophy, and the question has been raised whether it manages to escape its own criticisms. The answer depends on what is meant by skepticism. Historically, the term refers to a variety of different views and practices. But however it is understood, skepticism represents a challenge to the claim that human beings possess or can acquire knowledge.

In giving even this minimal characterization, it is important to emphasize that skeptics and nonskeptics alike accept the same definition of knowledge, one that implies two things: (1) if A knows that p, then p is true, and (2) if A knows that p, then A cannot be mistaken—*i.e.*, it is logically impossible that he is wrong. Thus, if a person says that he knows Smith will arrive at nine o'clock and Smith does not arrive at nine o'clock, then that person must withdraw his claim to know. He might say instead that he thought he knew or that he felt sure, but he cannot rationally continue to insist that he knew if what he claimed to know turns out to be false.

Given this definition of knowledge, it is not necessary for the skeptic to show that the person who claims to know that p is in fact mistaken; it is enough to show that a mistake is logically possible. This condition corresponds to clause (2) above. If the skeptic can establish that this clause is false in the case of a person's claim to know that p, he will have proved that the person does not know that p. Thus arises the skeptic's practice of searching for counterexamples to ordinary knowledge claims.

One variety of radical skepticism claims that there is no such thing as knowledge of an external world. According to this view, it is at least logically possible that one is merely a brain in a vat and that one's sense experiences of apparently real objects (*e.g.*, the sight of a tree) are produced by carefully engineered electrical stimulations. Again, given the definition of knowledge above, this kind of argument is sound, because it shows that there is a logical gap between knowledge claims about the external world and the sense experiences that can be adduced as evidence to support them. No matter how much evidence of this sort one has, it is always logically possible that the corresponding knowledge claim is false. (Av.S.)

The history of epistemology

ANCIENT PHILOSOPHY

The pre-Socratics. The central focus of ancient Greek philosophy was the problem of motion. Many pre-Socratic philosophers thought that no logically coherent account of motion and change could be given. Although this problem was primarily a concern of metaphysics, not epistemology, it had the consequence that all major Greek philosophers held that knowledge must not itself change or be changeable in any respect. This requirement motivated Parmenides (fl. 5th century BC), for example, to hold that thinking is identical with "being" (*i.e.*, all objects of thought exist and are unchanging) and that it is impossible to think of "nonbeing" or "becoming" in any way.

Parmenides

Plato. Plato accepted the Parmenidean constraint that knowledge must be unchanging. One consequence of this view, as Plato pointed out in *Theaetetus*, is that sense experience cannot be a source of knowledge, because the objects apprehended through it are subject to change. To the extent that humans have knowledge, they attain it by transcending sense experience in order to discover unchanging objects through the exercise of reason.

The Platonic theory of knowledge thus contains two

parts: first, an investigation into the nature of unchanging objects and, second, a discussion of how these objects can be known through reason. Of the many literary devices Plato used to illustrate his theory, the best known is the allegory of the cave, which appears in Book VII of the *Republic.* The allegory depicts people living in a cave, which represents the world of sense-experience. In the cave people see only unreal objects, shadows, or images. Through a painful intellectual process, which involves the rejection and overcoming of the familiar sensible world, they begin an ascent out of the cave into reality. This process is the analogue of the exercise of reason, which allows one to apprehend unchanging objects and thus to acquire knowledge. The upward journey, which few people are able to complete, culminates in the direct vision of the Sun, which represents the source of knowledge.

Plato's investigation of unchanging objects begins with the observation that every faculty of the mind apprehends a unique set of objects: hearing apprehends sounds, sight apprehends visual images, smell apprehends odours, and so on. Knowing also is a mental faculty, according to Plato, and therefore there must be a unique set of objects that it apprehends. Roughly speaking, these objects are the entities denoted by terms that can be used as predicates—*e.g.,* "good," "white," and "triangle." To say "This is a triangle," for example, is to attribute a certain property, that of being a triangle, to a certain spatiotemporal object, such as a figure drawn in the sand. Plato is here distinguishing between specific triangles that are drawn or painted and the common property they share, that of being triangular. Objects of the former kind, which he calls "particulars," are always located somewhere in space and time—*i.e.,* in the world of appearance. The property they share is a "form" or "idea" (the latter term is not used in any psychological sense). Unlike particulars, forms do not exist in space and time; moreover, they do not change. They are thus the objects that one apprehends when one has knowledge.

The dialectical method

Reason is used to discover unchanging forms through the method of dialectic, which Plato inherited from his teacher Socrates. The method involves a process of question and answer designed to elicit a "real definition." By a real definition Plato means a set of necessary and sufficient conditions that exactly determine the entities to which a given concept applies. The entities to which the concept "being a brother" applies, for example, are determined by the concepts "being male" and "being a sibling": it is both necessary and sufficient for a person to be a brother that he be male and a sibling. Anyone who grasps these conditions understands precisely what being a brother is.

In the *Republic,* Plato applies the dialectical method to the concept of justice. In response to a proposal by Cephalus that "justice" means the same as "honesty in word and deed," Socrates points out that, under some conditions, it is just not to tell the truth or to repay debts. Suppose one borrows a weapon from a person who later loses his sanity. If the person then demands his weapon back in order to kill someone who is innocent, it would be just to lie to him, stating that one no longer had the weapon. Therefore, "justice" cannot mean the same as "honesty in word and deed." By this technique of proposing one definition after another and subjecting each to possible counterexamples, Socrates attempts to discover a definition that cannot be refuted. In doing so he apprehends the form of justice, the common feature that all just things share.

Plato's search for definitions and, thereby, forms is a search for knowledge. But how should knowledge in general be defined? In the *Theaetetus* Plato argues that, at a minimum, knowledge involves true belief. No one can know what is false. A person may believe that he knows something, which is in fact false, but in that case he does not really know, he only thinks he knows. But knowledge is more than simply true belief. Suppose that someone has a dream in April that there will be an earthquake in September, and on the basis of his dream he forms the belief that there will be an earthquake in September. Suppose also that in fact there is an earthquake in September. The person has a true belief about the earthquake, but not knowledge of it. What he lacks is a good reason to support his true belief. In a word, he lacks justification. Using arguments such as these, Plato contends that knowledge is justified true belief.

Aristotle. In the *Posterior Analytics,* Aristotle (384–322 BC) claims that each science consists of a set of first principles, which are necessarily true and knowable directly, and a set of truths, which are both logically derivable from and causally explained by the first principles. The demonstration of a scientific truth is accomplished by means of a series of syllogisms—a form of argument invented by Aristotle—in which the premises of each syllogism in the series are justified as the conclusions of earlier syllogisms. In each syllogism, the premises not only logically necessitate the conclusion (*i.e.,* the truth of the premises makes it logically impossible for the conclusion to be false) but causally explain it as well. Thus, in the syllogism

The Aristotelian syllogism

All stars are distant objects
All distant objects twinkle
Therefore, all stars twinkle

the fact that stars twinkle is explained by the fact that all distant objects twinkle and the fact that stars are distant objects. The premises of the first syllogism in the series are first principles, which do not require demonstration, and the conclusion of the final syllogism is the scientific truth in question.

Much of what Aristotle says about knowledge is part of his doctrine about the nature of the soul, and in particular the human soul. As he uses the term, the soul (*psyche*) of a thing is what makes it alive; thus, every living thing, including plant life, has a soul. The mind or intellect (*nous*) can be described variously as a power, faculty, part, or aspect of the human soul. It should be noted that for Aristotle "soul" and "intellect" are scientific terms.

In an enigmatic passage, Aristotle claims that "actual knowledge is identical with its object." By this he seems to mean something like the following. When a person learns something, he "acquires" it in some sense. What he acquires must be either different from the thing he knows or identical with it. If it is different, then there is a discrepancy between what he has in mind and the object of his knowledge. But such a discrepancy seems to be incompatible with the existence of knowledge. For knowledge, which must be true and accurate, cannot deviate from its object in any way. One cannot know that blue is a colour, for example, if the object of that knowledge is something other than that blue is a colour. This idea, that knowledge is identical with its object, is dimly reflected in the modern formula for expressing one of the necessary conditions of knowledge: A knows that p only if it is true that p.

To assert that knowledge and its object must be identical raises a question: In what way is knowledge "in" a person? Suppose that Smith knows what dogs are—*i.e.,* he knows what it is to be a dog. Then, in some sense, dogs, or being a dog, must be in the mind of Smith. But how can this be? Aristotle derives his answer from his general theory of reality. According to him, all (terrestrial) substances are composed of two principles: form and matter. All dogs, for example, consist of a form—the form of being a dog—and matter, which is the stuff out of which they are made. The form of an object makes it the kind of thing it is. Matter, on the other hand, is literally unintelligible. Consequently, what is in the knower when he knows what dogs are is just the form of being a dog.

Form and matter

In his sketchy account of the process of thinking in *De anima* (*On the Soul*), Aristotle says that the intellect, like everything else, must have two parts: something analogous to matter and something analogous to form. The first of these is the passive intellect; the second is active intellect, of which Aristotle speaks tersely. "Intellect in this sense is separable, impassible, unmixed, since it is in its essential nature activity. . . . When intellect is set free from its present conditions it appears as just what it is and nothing more: it alone is immortal and eternal . . . and without it nothing thinks."

This part of Aristotle's views about knowledge is an extension of what he says about sensation. According to him, sensation occurs when the sense organ is stimulated by the sense object, typically through some medium, such as light for vision and air for hearing. This stimulation causes a

"sensible species" to be generated in the sense organ itself. This species is some sort of representation of the object sensed. As Aristotle describes the process, the sense organ receives "the form of sensible objects without the matter, just as the wax receives the impression of the signet-ring without the iron or the gold."

Ancient Skepticism. After the death of Aristotle the next significant development in the history of epistemology was the rise of Skepticism, of which there were at least two kinds. The first, Academic Skepticism, arose in the Academy (the school founded by Plato) in the 3rd century BC and was propounded by the Greek philosopher Arcesilaus (*c.* 315–*c.* 240 BC), about whom Cicero (106–43 BC), Sextus Empiricus (fl. 3rd century AD), and Diogenes Laërtius (fl. 3rd century AD) provide information. The Academic Skeptics, who are sometimes called "dogmatic," argued that nothing could be known with certainty. This form of Skepticism seems susceptible to the objection, raised by the Stoic Antipater (fl. *c.* 135 BC) and others, that the view is self-contradictory. To know that knowledge is impossible is to know something; hence, dogmatic Skepticism must be false.

Carneades (*c.* 213–129 BC), also a member of the Academy, developed a subtle reply to this charge. Academic Skepticism, he insisted, is not a theory about knowledge or the world but rather a kind of argumentative strategy. According to this strategy, the skeptic does not try to prove that he knows nothing. Instead, he simply assumes that he knows nothing and defends that assumption against attack. The burden of proof, in other words, is on those who believe that knowledge is possible.

Pyrrhonism

Carneades' interpretation of Academic Skepticism renders it very similar to the other major kind, Pyrrhonism, which takes its name from Pyrrho of Elis (*c.* 365–275 BC). Pyrrhonists, while not asserting or denying anything, attempted to show that one ought to suspend judgment and avoid making any knowledge claims at all, even the negative claim that nothing is known. The Pyrrhonist's strategy was to show that, for every proposition supported by some evidence, there is an opposite proposition supported by evidence that is equally good. Arguments like these, which are designed to refute both sides of an issue, are known as "tropes." The judgment that a tower is round when seen at a distance, for example, is contradicted by the judgment that the tower is square when seen up close. The judgment that Providence cares for all things, which is supported by the orderliness of the heavenly bodies, is contradicted by the judgment that many good people suffer misery and many bad people enjoy happiness. The judgment that apples have many properties—shape, colour, taste, and aroma—each of which affects a sense organ, is contradicted by the possibility that apples have only one property that affects each sense organ differently.

What is at stake in these arguments is "the problem of the criterion"—*i.e.,* the problem of determining a justifiable standard against which to measure the worth or validity of judgments, or claims to knowledge. According to the Pyrrhonists, every possible criterion is either groundless or inconclusive. Thus, suppose that something is offered as a criterion. The Pyrrhonist will ask what justification there is for it. If no justification is offered, then the criterion is groundless. If, on the other hand, a justification is produced, then the justification itself is either justified or it is not. If it is not justified, then again the criterion is groundless. If it is justified, then there must be some criterion that justifies it. But this is just what the dogmatist was supposed to have provided in the first place.

If the Pyrrhonist needed to make judgments in order to survive, he would be in trouble. In fact, however, there is a way of living that bypasses judgment. He can live quite nicely, according to Sextus, by following custom and accepting things as they appear to him. In doing so, he does not judge the correctness of anything but merely accepts appearances for what they are.

Ancient Pyrrhonism is not strictly an epistemology, since it has no theory of knowledge and is content to undermine the dogmatic epistemologies of others, especially Stoicism and Epicureanism. Pyrrho himself was said to have had ethical motives for attacking dogmatists: being reconciled to not knowing anything, Pyrrho thought, induced serenity (*ataraxia*).

St. Augustine. St. Augustine of Hippo (354–430) claimed that human knowledge would be impossible if God did not "illumine" the human mind and thereby allow it to see, grasp, or understand ideas. Ideas as Augustine construed them are like Plato's—timeless, immutable, and accessible only to the mind. They are indeed in some mysterious way a part of God and seen in God. Illumination, the other element of the theory, was for Augustine and his many followers, at least through the 14th century, a technical notion, built upon a visual metaphor inherited from Plotinus (205–270) and other Neoplatonic thinkers. According to this view, the human mind is like an eye that can see when and only when God, the source of light, illumines it. Varying his metaphor, Augustine sometimes says that the human mind "participates" in God and even that Christ illumines the mind by dwelling in it. It is important to emphasize that Augustine's theory of illumination concerns all knowledge, and not specifically mystical or spiritual knowledge.

Augustine's refutation of Skepticism

Before he articulated this theory in his mature years, soon after his conversion to Christianity, Augustine was concerned to refute the Skepticism of the Academy. In *Against the Academicians* (386) he claimed that, if nothing else, humans know disjunctive tautologies such as "Either there is one world or there is not one world" and "Either the world is finite or it is infinite." Humans also know many propositions that begin with the phrase "It appears to me that," such as "It appears to me that what I perceive is made up of earth and sky, or what appears to be earth and sky." Furthermore, they know logical (or what he calls "dialectical") propositions—for example, "If there are four elements in the world, there are not five," "If there is one sun, there are not two," "One and the same soul cannot die and still be immortal," and "Man cannot at the same time be happy and unhappy."

Many other refutations of Skepticism occur in Augustine's later works, notably *On the Free Choice of the Will* (389–395), *On the Trinity* (399/400–416/421), and *The City of God* (413–426/427). In the last of these, Augustine proposes other examples of things about which people can be absolutely certain. Again in explicit refutation of the Skeptics of the Academy, he argues that, if a person is deceived, then it is certain that he exists. Expressing the point in the first person, as René Descartes (1596–1650) did some 1,200 years later, Augustine says, "If I am deceived, then I exist" (*Si fallor, sum*). A variation on this line of reasoning appears in *On the Trinity,* where he argues that, if he is deceived, he is at least certain that he is alive.

Anticipations of Descartes

Augustine also points out that, since he knows, he knows that he knows; and he notes that this can be reiterated an infinite number of times: If I know that I know that I am alive, then I know that I know that I know that I am alive. In 20th-century epistemic logic, this thesis was codified as the axiom "If A knows that *p,* then A knows that A knows that *p.*" In *The City of God* Augustine claims that he knows that he loves: "For neither am I deceived in this, that I love, since in those things which I love I am not deceived." With Skepticism thus refuted, Augustine simply denies that he has ever been able to doubt what he has learned through his sensations or even through the testimony of most people.

Augustine's Platonic epistemology dominated the Middle Ages until the mid-13th century, when St. Albertus Magnus (1200–80) and his student St. Thomas Aquinas (1224/25–74) developed an alternative to Augustinian illuminationism.

MEDIEVAL PHILOSOPHY

St. Anselm of Canterbury. The phrase that St. Anselm of Canterbury (*c.* 1033–1109) used to describe his philosophy—namely, "faith seeking reason" (*fides quaerens intellectum*)—well characterizes medieval philosophy as a whole. All the great medieval philosophers—Christian, Jewish, and Islāmic alike—were also theologians. Virtually every object of interest was related to their belief in God, and virtually every solution to every problem, including the problem of knowledge, contained God as an essential

part. Indeed, Anselm himself equated truth and intelligibility with God. As he noted at the beginning of his *Proslogium* (1077–78), however, there is a tension between the view that God is truth and intelligibility and the fact that humans have no perception of God. How can there be knowledge of God, he asks, when all knowledge comes through the senses, and God, being immaterial, cannot be sensed? His answer is to distinguish between knowing something by being acquainted with it through sensation and knowing something through a description. Knowledge by description is possible using concepts formed on the basis of sensation. Thus, all knowledge of God depends upon the description that he is "the thing than which a greater cannot be conceived." From this premise Anselm infers, in his ontological argument for the existence of God, that humans can know that there exists a God that is all-powerful, all-knowing, all-just, all-merciful, and immaterial. Eight hundred years later, Russell developed an epistemological theory based on a similar distinction between knowledge by acquaintance and knowledge by description, though he would have vigorously denied that the distinction could be used to show that God exists.

St. Thomas Aquinas. With the translation into Latin of Aristotle's *On the Soul* in the early 13th century, the Platonic and Augustinian epistemology that dominated the early Middle Ages was gradually displaced. Following Aristotle, Aquinas recognized different kinds of knowledge. Sensory knowledge arises from sensing particular things. Because it has individual things as its object and is shared with brute animals, however, sensory knowledge is a lower form of awareness than scientific knowledge, which is characterized by generality. To say that scientific knowledge is characteristically general is not to diminish the importance of specificity: scientific knowledge also should be rich in detail, and God's knowledge is the most detailed of all. The detail, however, must be essential to the kind of thing being studied and not peculiar to certain instances of it. Aquinas thought that, though the highest knowledge humans can possess is knowledge of God, knowledge of physical objects is better suited to human capabilities. Only this kind of knowledge will be considered here.

Aquinas' discussion of knowledge in the *Summa theologiae* is an elaboration on the thought of Aristotle. Aquinas claims that knowledge is obtained when the active intellect abstracts a concept from an image received from the senses. In one account of this process, abstraction is the act of isolating from an image of a particular object the elements that are essential to its being an object of that kind. From the image of a dog, for example, the intellect abstracts the ideas of being alive, being capable of reproduction and movement, and whatever else might be essential to being a dog. These ideas are distinguished from ideas of properties that are peculiar to particular dogs, such as the property of weighing 20 pounds.

As stated earlier, Aristotle typically spoke of the form of an object as being in the mind or intellect of the knower and the matter as being outside it. Although it was necessary for Aristotle to say something like this in order to escape the absurdity of holding that material objects exist in the mind exactly as they do in the physical world, there is something unsatisfying about it. Physical things contain matter as an essential element, and, if their matter is no part of what is known, then human knowledge is incomplete. In order to counter this worry, Aquinas revised Aristotle's theory to say that not only the form but also the "species" of an object is in the intellect. A species is a combination of form and something like a general idea of matter, which Aquinas called "common matter." Common matter is contrasted with "individuated matter," which is the stuff that comprises the physical bulk of an object.

Species

One objection to this theory is that it seems to entail that the objects of human knowledge are ideas rather than things. That is, if knowing a thing consists of having its form and species in one's intellect, then it appears that the form and species, not the thing, is what is known. It might seem, then, that Aquinas' view is a type of idealism.

Aquinas had anticipated this kind of criticism in a number of ways. In order to meet it, he introduced a distinction between what is known and that by which what is known is known. To specify what is known—say, an individual dog—is to specify the object of knowledge; to specify that by which what is known is known—say, the image or the species of a dog—is to specify the apparatus of knowledge. Thus the species of a thing that is known is not itself an object of knowledge, though it can become an object of knowledge by being reflected upon.

John Duns Scotus. Although he accepted some aspects of Aristotelian abstractionism, John Duns Scotus (*c.* 1266–1308) did not base his account of human knowledge on this alone. According to him, there are four classes of things that can be known with certainty. First, there are things that are knowable *simpliciter*, including true identity statements such as "Cicero is Tully" and propositions, later called analytic, such as "Man is rational." Duns Scotus claims that such truths "coincide" with that which makes them true. One consequence of this view is that the negation of a simple truth is always inconsistent, even if it is not explicitly contradictory. The negation of "The whole is greater than any proper part," for example, is not explicitly contradictory, as is "Snow is white and snow is not white." Nevertheless it is inconsistent, because there is no possible situation in which it is true.

The second class consists of things that are known through experience, where "experience" is understood in an Aristotelian sense implying numerous encounters. The knowledge afforded by experience is inductive, grounded in the principle that "whatever occurs in a great many instances by a cause that is not free is the natural effect of that cause." It is important to note that Duns Scotus' confidence in induction did not survive the Middle Ages. Nicholas of Autrecourt (1300–50), whose views anticipated the radical skepticism of Hume, argued at length that no amount of observed correlation between two types of events is sufficient to establish a necessary causal connection between them, and thus that inferences based on causal assumptions are never rationally justified.

The third class consists of things that directly concern one's own actions. Humans who are awake, for example, know immediately and with certainty—and not through any inference—that they are awake; similarly, they know with certainty that they think and that they see and hear and have other sense experiences. Even if a sense experience is caused by a defective sense organ, it remains true that one is directly aware of the content of the sensation. When one has the sensation of seeing a round object, for example, one is directly aware of the roundness, even if the thing one is seeing is not really round.

Finally, the fourth class contains things that are knowable through the human senses. Apparently unconcerned by the threat of Skepticism, Duns Scotus maintained that sensation affords knowledge of the heavens, the earth, the sea, and all the things that are in them.

Intuitive and abstractive cognition

Duns Scotus' most important contribution to epistemology is his distinction between "intuitive" and "abstractive" cognition. Intuitive cognition is the immediate and indubitable awareness of the existence of a thing. It is knowledge "precisely of a present object [known] as being present and of an existent object [known] as being existent." If a person sees Socrates before him, then, according to Duns Scotus, he has intuitive knowledge of the proposition that Socrates exists and of the proposition that Socrates is the cause of that knowledge. Abstractive cognition, in contrast, is knowledge about a thing that is abstracted from, or logically independent of, that thing's actual existence or nonexistence.

William of Ockham. Several parts of Duns Scotus' account are vulnerable to Skeptical challenges—*e.g.*, his endorsement of the certainty of knowledge based on sensation and his claim that intuitive knowledge of an object guarantees its existence. William of Ockham (*c.* 1285–1349?) radically revised Duns Scotus' theory of intuitive knowledge. Unlike Duns Scotus, Ockham did not require the object of intuitive knowledge to exist; nor did he hold that intuitive knowledge must be caused by its object. To the question, "What is the distinction between intuitive and abstractive knowledge?," Ockham answered that they are simply different. His answer notwithstanding, it is characteristic of intuitive knowledge, according to Ockham,

that it is unmediated. There is no gap between the knower and the known that might undermine certainty: "I say that the thing itself is known immediately without any medium between itself and the act by which it is seen or apprehended."

According to Ockham, there are two kinds of intuitive knowledge: natural and supernatural. In cases of natural intuitive knowledge, the object exists, the knower judges that the object exists, and the object causes the knowledge. In cases of supernatural intuitive knowledge, the object does not exist, the knower judges that the object does not exist, and God is the cause of the knowledge.

Ockham recognized that God might cause a person to think that he has intuitive knowledge of an existent object when in fact there is no such object. But this would be a case of false belief, he contends, not intuitive knowledge. Unfortunately, by acknowledging that there is no way to distinguish between genuine intuitive knowledge and divine counterfeits, Ockham effectively conceded the issue to the Skeptics.

Later medieval philosophy followed a fairly straight path toward Skepticism. John of Mirecourt (fl. 14th century) was censured by the University of Paris in 1347 for maintaining, among other things, that external reality cannot be known with certainty because God can cause illusions to seem real. A year earlier, Nicholas of Autrecourt was condemned by Pope Clement VI for holding that one can have certain knowledge only of the logical principles of identity and contradiction and the immediate reports of sensation. As noted above, he denied that causal relations exist; he also denied the reality of substance.

Scientific theology to secular science. For most of the Middle Ages there was no distinction between theology and science (*scientia*). Science was knowledge that was deduced from self-evident principles, and theology received its principles from God, the source of all principles. By the 14th century, however, scientific and theological thinking began to diverge. Roughly speaking, theologians began to argue that human knowledge was narrowly circumscribed. They often invoked the omnipotence of God in order to undercut the pretensions of human reason, and in place of rationalism in theology they promoted a kind of fideism (*i.e.*, a philosophy based entirely on faith).

Gregory of Rimini

The Italian theologian Gregory of Rimini (d. 1358) exemplified this development. Inspired by Ockham, Gregory argued that, whereas science concerns what is accessible to humans through natural means—*i.e.*, sensation and intelligence—theology deals with what is accessible only in a supernatural way. Thus, theology is not scientific. The role of theology is to explain the meaning of the Bible and the articles of faith and to deduce conclusions from them. Since the credibility of the Bible rests upon belief in divine revelation, theology lacks a rational foundation. Furthermore, since there is neither self-evident knowledge of God nor any natural experience of him, humans can have only an abstract understanding of what he is.

Ockham and Gregory did not intend their views to undermine theology. To the contrary, for them, theology is in a sense more certain than science, because it is built upon principles that are guaranteed to be true by God, whereas the principles of science must be as fallible as their human creators. Unfortunately for theology, the prestige of science increased in the 16th century and skyrocketed in the 17th and 18th centuries. Modern thinkers preferred to reach their own conclusions using reason and experience, even if ultimately these conclusions did not have the authority of God to support them. As theologians lost confidence in reason, other thinkers, who had little or no commitment to Aristotelian thought, became its champions, thus furthering the development of modern science.

MODERN PHILOSOPHY

Faith and reason. Although modern philosophers as a group are usually thought to be purely secular thinkers, in fact nothing could be further from the truth. From the early 17th century until the middle of the 18th century, all the great philosophers incorporated substantial religious elements into their work. In his *Meditations* (1641), Descartes offered two distinct proofs of the existence of God and asserted that no one who does not have a rationally well-founded belief in God can have knowledge in the proper sense of the term. Benedict de Spinoza (1632–77) began his *Ethics* (1677) with a proof of God's existence and then discussed at length its implications for understanding all reality. And George Berkeley (1685–1753) explained the apparent stability of the sensible world by appealing to God's constant thought of it.

Among the reasons modern philosophers are mistakenly thought to be primarily secular thinkers is that many of their epistemological principles, including some that were designed to defend religion, were later interpreted as subverting the rationality of religious belief. The views of Thomas Hobbes (1588–1679) might briefly be considered in this connection. In contrast to the standard view of the Middle Ages that propositions of faith are rational, Hobbes argued that such propositions belong not to the intellect but to the will. The significance of religious propositions, in other words, lies not in what they say but in how they are used. To profess a religious proposition is not to assert a factual claim about the world but merely to give praise and honour to God and to obey the commands of lawful religious authorities. Indeed, one does not even need to understand the meanings of the words in the proposition in order for this function to be fulfilled: simply mouthing them is sufficient.

Thomas Hobbes

In *An Essay Concerning Human Understanding* (1690), John Locke further eroded the intellectual status of religious propositions by making them subordinate to reason in several respects. First, reason can restrict the possible content of propositions allegedly revealed by God; in particular, no proposition of faith can be a contradiction. Furthermore, because no revelation can contain an idea not derived from sense experience, we should not believe St. Paul when he speaks of experiencing things as "eye hath not seen, nor ear heard, nor hath it entered into the heart of man to conceive . . ." Another respect in which reason takes precedence over faith is that knowledge based on immediate sense experience (what Locke calls "intuitive knowledge") is always more certain than any alleged revelation. Thus, a person who sees that someone is dead cannot have it revealed to him that the person is at that moment alive. Rational proofs in mathematics and science also cannot be controverted by revelation. The interior angles of a rectangle equal 360°, and no alleged revelation to the contrary is credible. In short, "*Nothing that is contrary to, and inconsistent with, the clear and self-evident dictates of reason, has a right to be urged or assented to as a matter of faith.*"

What space, then, does faith occupy in the mansion of human beliefs? According to Locke, it shares a room with probable truths, which are propositions of which reason cannot be certain. There are two types of probable truth: that which concerns observable matters of fact, and that which goes "beyond the discovery of our sense." Religious propositions can belong to either category, as can empirical and scientific propositions. Thus the propositions "Caesar crossed the Rubicon" and "Jesus walked on water" belong to the first category, because they make claims about events that would be observable if they occurred; on the other hand, propositions like "Heat is caused by the friction of imperceptibly small bodies" and "Angels exist" belong to the second category, because they concern entities that by definition cannot be objects of sense experience.

Although it might seem that Locke's mixing of religious and scientific claims helped to secure a place for the former, in fact it did not. For Locke also held that "reason must judge" whether or not something is a revelation and more generally that "*Reason must be our last judge and guide in everything.*" Although this maxim was intended to reconcile reason and revelation, over the course of 200 years reason repeatedly judged that alleged revelations had no scientific or intellectual standing.

Despite the strong religious elements in the thought of modern philosophers, especially those writing before the middle of the 18th century, contemporary epistemologists have been interested only in the purely secular aspects of their work. Accordingly, these aspects will predominate in the following discussion.

Epistemology and modern science. The Polish astronomer Nicolaus Copernicus (1473–1543) argued in *On the Revolutions of the Celestial Spheres* (1543) that the Earth revolves around the Sun. His theory was epistemologically shocking for at least two reasons. First, it directly contradicted the way in which humans experienced their relation to the Sun, and in doing so it made ordinary nonscientific reasoning about the world seem unreliable—indeed, like a kind of superstition. Second, it contradicted the account presented in several books of the Bible, most importantly the story in Genesis of the structure of the cosmos, according to which the Earth is at the centre of creation. If Copernicus were right, then the Bible could no longer be treated as a source of scientific knowledge.

Galileo

Many of the discoveries of the Italian astronomer Galileo Galilei (1564–1642) were equally unsettling. His telescope seemed to reveal that unaided human vision gives false, or at least seriously incomplete, information about the nature of celestial bodies. In addition, his mathematical descriptions of physical phenomena indicated that much of our sense experience of these phenomena contributes nothing to our knowledge of them.

Another counterintuitive theory of Galileo was his distinction between the "primary" and the "secondary" qualities of an object. Whereas primary qualities—such as figure, quantity, and motion—are genuine properties of things and are knowable by mathematics, secondary qualities—such as colour, odour, taste, and sound—exist only in human consciousness and are not part of the objects to which they are normally attributed.

René Descartes. Both the rise of modern science and the rediscovery of Skepticism were important influences on Descartes. Although he believed that certain knowledge was possible and that modern science would one day enable humans to become the masters of nature, he also thought that Skepticism presented a legitimate challenge that needed an answer, one that only he could provide.

The challenge of Skepticism, as Descartes saw it, is vividly described in his *Meditations.* He considered the possibility that an "evil genius" with extraordinary powers has deceived him to such an extent that all his beliefs are false. But it is not possible, Descartes contended, that all his beliefs are false, for if he has false beliefs, he is thinking, and if he is thinking, then he exists. Therefore, his belief that he exists cannot be false, as long as he is thinking. This line of argument is summarized in the formula *Cogito, ergo sum* ("I think, therefore I am").

Cogito, ergo sum

Descartes distinguished two sources of knowledge: intuition and deduction. Intuition is an unmediated mental "seeing," or direct apprehension. Descartes's intuition of his own thinking guarantees that his belief that he is thinking is true. Although his formula might suggest that his belief that he exists is guaranteed by deduction rather than intuition (because it contains the term "therefore"), in the *Objections and Replies* (1642) he states explicitly that the certainty of this belief also is based upon intuition.

If one could know only that one thinks and that one exists, human knowledge would be depressingly meager. Accordingly, Descartes attempted to broaden the limits of knowledge by proving to his own satisfaction that God exists; that the standard for knowing something is having a "clear and distinct" idea of it; that mind is more easily known than body; that the essence of matter is extension; and, finally, that most of his former beliefs are true.

Unfortunately for Descartes, few people were convinced by these arguments. One major problem with them is known as the "Cartesian circle." Descartes's argument to show that his knowledge extends beyond his own existence depends upon the claim that whatever he perceives "clearly and distinctly" is true. This claim in turn is supported by his proof of the existence of God, together with the assertion that God, because he is not a deceiver, would not cause Descartes to be deceived in what he clearly and distinctly perceives. But because the criterion of clear and distinct perception presupposes the existence of God, Descartes cannot rely upon it in order to guarantee that he was not deceived (*i.e.,* that he did not make a mistake) in the course of proving that God exists. Therefore, he does not know that his proof is cogent. But if he does not know this, then he cannot use the criterion of clear and distinct perception to show that he knows more than that he exists.

John Locke. As mentioned above, whereas rationalist philosophers such as Descartes held that the ultimate source of human knowledge is reason, empiricists such as Locke argued that it is experience. Rationalist accounts of knowledge also typically involved the claim that at least some kinds of ideas are "innate," or present in the mind at (or even before) birth. For philosophers such as Descartes and Gottfried Wilhelm Leibniz (1646–1716), the hypothesis of innateness is required in order to explain how humans come to have ideas of certain kinds. These ideas include not only mathematical concepts such as numbers, which appear not to be derived from sense experience, but also, according to some philosophers, certain general metaphysical principles, such as "every event has a cause."

Locke claimed that this line of argument has no force. He held that all ideas (except those that are "trifling") can be explained in terms of experience. Instead of attacking the doctrine of innate ideas directly, however, his strategy was to refute it by showing that it is explanatorily otiose and hence dispensable.

There are two kinds of experience, according to Locke: observation of external objects—*i.e.,* sensation—and observation of the internal operations of the mind. Locke called this latter kind of experience, for which there is no natural word in English, "reflection." Some examples of reflection are perceiving, thinking, doubting, believing, reasoning, knowing, and willing.

As Locke uses the term, a "simple idea" is anything that is an "immediate object of perception" (*i.e.,* an object as it is perceived by the mind) or anything that the mind "perceives *in itself*" through reflection. Simple ideas, whether they are ideas of perception or ideas of reflection, may be combined or repeated to produce "compound ideas," as when the compound idea of an apple is produced by bringing together simple ideas of a certain colour, shape, texture, odour, and figure. Abstract ideas are created when "ideas taken from particular beings become general representatives of all of the same kind."

The "qualities" of an object are its powers to cause ideas in the mind. One consequence of this usage is that, in Locke's epistemology, words designating the sensible properties of objects are systematically ambiguous. The word *red,* for example, can mean either the idea of red in the mind or the quality in an object that causes that idea. Locke distinguishes between primary and secondary qualities, as Galileo did. According to Locke, primary qualities, but not secondary qualities, are represented in the mind as they exist in the object itself. The primary qualities of an object, in other words, resemble the ideas they cause in the mind. Examples of primary qualities include "solidity, extension, figure, motion, or rest, and number." Secondary qualities are configurations or arrangements of primary qualities that cause sensible ideas such as sounds, colours, odours, and tastes. Thus, according to Locke's view, the phenomenal redness of a fire engine is not in the fire engine itself, but its phenomenal solidity is. Similarly, the phenomenal sweet odour of a rose is not in the rose itself, but its phenomenal extension is.

In Book IV of the *Essay Concerning Human Understanding,* Locke defines knowledge as "*the perception of the connexion of and agreement, or disagreement and repugnancy of any of our ideas.*" Knowledge so defined admits of three degrees, according to Locke. The first is what he calls "intuitive knowledge," in which the mind "perceives the agreement or disagreement of two ideas *immediately by themselves,* without the intervention of any other." Although Locke's first examples of intuitive knowledge are analytic propositions such as "*white* is not *black,*" "a *circle* is not a *triangle,*" and "*three* are more than *two,*" later he says that "the knowledge of our own being we have by intuition." Relying on the metaphor of light as Augustine and others had, Locke says of this knowledge that "the mind is presently filled with the clear light of it. *It is on this intuition that depends all the certainty and evidence of all our knowledge.*"

Three degrees of knowledge

The second degree of knowledge obtains when "the mind perceives the agreement or disagreement of . . . ideas, but

not immediately." In these cases, some mediating idea makes it possible to see the connection between two other ideas. In a demonstration (or proof), for example, the connection between any premise and the conclusion is mediated by other premises and by the laws of logic. Demonstrative knowledge, although certain, is not as certain as intuitive knowledge, according to Locke, because it requires effort and attention to go through the steps needed to recognize the certainty of the conclusion.

A third degree of knowledge, "sensitive knowledge," is roughly the same as what Duns Scotus called "intuitive cognition," namely, the perception of "*the particular existence of finite beings without us.*" Unlike intuitive cognition, however, Locke's sensitive knowledge is not the most certain kind of knowledge it is possible to have. For him, it is less certain than intuitive or demonstrative knowledge.

Next in certainty to knowledge is probability, which Locke defines as the appearance of agreement or disagreement of ideas with each other. Like knowledge, probability admits of degrees, the highest of which attaches to propositions endorsed by the general consent of all people in all ages. Locke may have had in mind the virtually general consent of his contemporaries in the proposition that God exists, but he also explicitly mentions beliefs about causal relations.

The next-highest degree of probability belongs to propositions that hold not universally but for the most part, such as "people prefer their own private advantage to the public good." This sort of proposition is typically derived from history. A still lower degree of probability attaches to claims about specific facts, for example, that a man named Julius Caesar lived a long time ago. Problems arise when testimonies conflict, as they often do, but there is no simple rule or set of rules that determines how one ought to resolve such controversies.

Probability can concern not only objects of possible sense experience, as most of the foregoing examples do, but also things that are outside the sensible realm, such as angels, devils, magnetism, and molecules.

George Berkeley. The next great figure in the development of empiricist epistemology was George Berkeley (1685–1753). In his major work, *Treatise Concerning the Principles of Human Knowledge* (1710), Berkeley asserted that nothing exists except ideas and spirits (minds or souls). He distinguished three kinds of ideas: those that come from sense experience correspond to Locke's simple ideas of perception; those that come from "attending to the passions and operations of the mind" correspond to Locke's ideas of reflection; and those that come from compounding, dividing, or otherwise representing ideas correspond to Locke's compound ideas. By "spirit" Berkeley meant "one simple, undivided, active being." The activity of spirits consists of both understanding and willing: understanding is spirit perceiving ideas, and will is spirit producing ideas.

For Berkeley, physical objects such as tables and chairs are really nothing more than collections of sensible ideas. Since no idea can exist outside a mind, it follows that tables and chairs, as well all the other furniture of the physical world, exist only insofar as they are in the mind of someone—*i.e.*, only insofar as they are perceived. For any nonthinking being, *esse est percipi* ("to be is to be perceived").

Esse est percipi

The clichéd question of whether a tree falling in an uninhabited forest makes a sound is inspired by Berkeley's philosophy, though he never considered it in these terms. He did, however, consider the implicit objection and gave various answers to it. His most significant answer is that, when no human is perceiving a table or other such object, God is; and it is God's thinking that keeps the otherwise unperceived object in existence.

Although this doctrine initially strikes one as strange, Berkeley claimed that he was merely describing the commonsense view of reality. To say that colours, sounds, trees, dogs, and tables are ideas is not to say that they do not really exist, it is merely to say what they really are. Moreover, to say that animals and pieces of furniture are ideas is not to say that they are diaphanous, gossamer, and evanescent. Opacity, density, and permanence are also ideas that partially constitute these objects.

Berkeley supports his main thesis with a syllogistic argument: physical things—such as trees, dogs, and houses—are things perceived by sense; things perceived by sense are ideas; therefore, physical things are ideas. If one objects that the second premise of the syllogism is false—people sense things, not ideas—Berkeley would reply that there are no sensations without ideas and that it makes no sense to speak of some additional thing that ideas are supposed to represent or resemble. Unlike Locke, Berkeley did not believe that there is anything "behind" or "underlying" ideas in a world external to the mind. Indeed, Berkeley claims that no clear idea can be attached to this notion.

One consequence of this view is that Locke's distinction between primary and secondary qualities is spurious. Extension, figure, motion, rest, and solidity are as much ideas as green, loud, and bitter are; there is nothing special about the former kind of idea. Furthermore, matter, as philosophers conceive it, does not exist, and indeed it is contradictory. For matter is supposedly unsensed extension, figure, and motion; but since extension, figure, and motion are ideas, they must be sensed.

Berkeley's doctrine that things unperceived by human beings continue to exist in the thought of God was not novel. It was part of the traditional belief of Christian philosophers from Augustine through Aquinas and at least to Descartes that God not only creates all things but also keeps them in existence by thinking of them. According to this view, if God were ever to stop thinking of a creature, it would immediately be annihilated.

David Hume. Although Berkeley rejected the Lockean notions of primary and secondary qualities and matter, he retained Locke's beliefs in the existence of mind, substance, and causation as an unseen force or power in objects. Hume, in contrast, rejected all these notions.

Kinds of perception. Hume recognized two kinds of perception: "impressions" and "ideas." Impressions are perceptions that the mind experiences with the "most force and violence," and ideas are the "faint images" of impressions. Hume considered this distinction so obvious that he demurred from explaining it at any length: as he indicates in a summary explication in *A Treatise of Human Nature* (1739–40), impressions are felt, and ideas are thought. Nevertheless, he concedes that sometimes sleep, fever, or madness can produce ideas that approximate to the force of impressions, and some impressions can approach the weakness of ideas. But such occasions are rare.

Impressions and ideas

All perceptions, whether impressions or ideas, can be either simple or complex. Whereas simple perceptions are not subject to further separation or distinction, complex perceptions are. To return to an example mentioned above, the perception of an apple is complex, insofar as it consists of a combination of simple perceptions of a certain shape, colour, texture, and aroma. It is noteworthy that, according to Hume, for every simple impression there is a simple idea that corresponds to it and differs from it only in force and vivacity, and vice versa. Thus, corresponding to the impression of red is the idea of red. This correlation does not hold true in general for complex perceptions. Although there is a correspondence between the complex impression of an apple and the complex idea of an apple, there is no impression that corresponds to the idea of Pegasus or to the idea of a unicorn; these complex ideas do not have a correlate in reality. Similarly, there is no complex idea corresponding to the complex impression of, say, an extensive vista of the city of Rome.

Because the formation of every simple idea is always preceded by the experience of a corresponding simple impression, and because the experience of every simple impression is always followed by the formation of a corresponding simple idea, it follows, according to Hume, that simple impressions are the causes of their corresponding simple ideas.

There are two kinds of impressions: those of sensation and those of reflection. Regarding the former, Hume says little more than that sensation "arises in the soul originally from unknown causes." Impressions of reflection arise from a complicated series of mental operations. First, one experiences impressions of heat or cold, thirst or hunger, pleasure or pain; second, one forms corresponding ideas of

heat or cold, thirst or hunger, pleasure or pain; and third, one's reflection on these ideas produces impressions of "desire and aversion, hope and fear."

Because the faculty of imagination can divide and assemble disparate ideas at will, some explanation is needed for the fact that people tend to think in regular and predictable patterns. Hume says that the production of thoughts in the mind is guided by three principles: resemblance, contiguity, and cause and effect. Thus, a person who thinks of one idea is likely to think of another idea that resembles it; his thought is likely to run from red to pink to white or from dog to wolf to coyote. Concerning contiguity, people are inclined to think of things that are next to each other in space and time. Finally and most importantly, people tend to create associations between ideas of things that are causally related. The ideas of fire and smoke, parent and child, and disease and death are connected in the mind for this reason.

Hume uses the principle of resemblance for another purpose: to explain the nature of general ideas. Hume holds that there are no abstract ideas, and he affirms that all ideas are particular. Some of them, however, function as general ideas—*i.e.,* ideas that represent many objects of a certain kind—because they incline the mind to think of other ideas that they resemble.

Relations of ideas and matters of fact. According to Hume, the mind is capable of apprehending two kinds of proposition or truth: those expressing "relations of ideas" and those expressing "matters of fact." The former can be intuited—*i.e.,* seen directly—or deduced from other propositions. That *a* is identical with *a,* that *b* resembles *c,* and that *d* is larger than *e* are examples of propositions that are intuited. The negations of true propositions expressing relations of ideas are contradictory. Because the propositions of arithmetic and algebra are exclusively about relations of ideas, these disciplines are more certain than others. In the *Treatise,* Hume says that geometry is not quite as certain as arithmetic and algebra, because its original principles derive from sensation, and about sensation there can never be absolute certainty. He revised his views later, however, and in *An Enquiry Concerning Human Understanding* (1748) he put geometry on an equal footing with the other mathematical sciences.

Unlike propositions about relations of ideas, propositions about matters of fact are known only through experience. By far the most important of these propositions are those that express or presuppose causal relations—*e.g.,* "Fire causes heat" and "A moving billiard ball communicates its motion to any stationary ball it strikes." But how is it possible to know through experience that one kind of object or event causes another? What kind of experience would justify such a claim?

Cause and effect. In the *Treatise,* Hume observes that our idea of causation contains three components: contiguity (*i.e.,* near proximity) of time and place, temporal priority of the cause, and a more mysterious component, which he calls "necessary connection." In other words, when we say that *x* is a cause of *y,* we mean that instances of *x* and instances of *y* are always near each other in time and space, that instances of *x* occur before instances of *y,* and that there is some connection between *x*'s and *y*'s that makes it necessary that an instance of *y* occurs if an instance of *x* does.

Origin of the idea of causation

It is easy to explain the origin in experience of the first two components of the idea of causation. In our past experience, all events consisting of a moving billiard ball striking a stationary one were quickly followed by events consisting of the movement of the formerly stationary ball. In addition, the first sort of event always preceded the second, and never the reverse. But whence the third component of the idea of causation, whereby we think that the striking of the stationary ball somehow necessitates that it will move? We certainly have not seen or otherwise directly observed this necessity in past experience, as we have the contiguity and temporal order of the striking and moving of billiard balls.

It is important to note that, were it not for the idea of necessary connection, we would have no reason to believe that a currently observed cause will produce an unseen effect in the future or that a currently observed effect was produced by an unseen cause in the past. For the mere fact that past instances of the cause and effect were contiguous and temporally ordered in a certain way does not logically imply that present and future instances will display the same relations. (Such an inference could be justified only if one assumed a principle such as "*instances, of which we have had no experience, must resemble those, of which we have had experience, and that the course of nature continues always uniformly the same.*" The problem with this principle is that it too stands in need of justification, and the only possible justification is question-begging. That is, one could argue that present and future experience will resemble past experience, because, in the past, present and future experience resembled past experience. But this argument clearly assumes what it sets out to prove.)

Hume offers a "skeptical solution" of the problem of the origin of our idea of necessary connection. According to him, it arises from the feeling of "determination" that is created in the mind when it experiences the first member of a pair of events that it is long accustomed to experiencing together. When the mind observes the moving billiard ball strike the stationary one, it is moved by force of habit and custom to form an idea of the movement of the stationary ball—*i.e.,* to believe that the stationary ball will move. The feeling of being "carried along" in this process is the impression from which the idea of necessary connection is derived. Hume's solution is "skeptical" in the sense that, though it accounts for the origins of our idea of necessary connection, it does not make our causal inferences any more rational than they were before. The solution explains why we are psychologically compelled to form beliefs about future effects and past causes, but it does not justify those beliefs logically. It remains true that our only evidence for these beliefs is our past experience of contiguity and temporal precedence. "All inferences from experience, therefore, are effects of custom, not of reasoning." Thus custom, not reason, is the great guide of life.

Substance. From the time of Plato, one of the most basic notions in philosophy has been "substance"—that whose existence does not depend upon anything else. For Locke, the substance of an object is the hidden "substratum" in which the object's properties inhere and on which they depend for their existence. One of the reasons for Hume's importance in the history of philosophy is that he rejected this notion. In keeping with his strict empiricism, he held that the idea of substance, if it answers to anything genuine, must arise from experience. But what kind of experience can this be? By its proponents' own definition, substance is that which underlies an object's properties, including its sensible properties; it is therefore in principle unobservable. Hume concludes, "We have therefore no idea of substance, distinct from that of a collection of particular qualities, nor have we any other meaning when we either talk or reason concerning it." Furthermore, the things that earlier philosophers had assumed were substances are in fact "nothing but a collection of simple ideas, that are united by the imagination, and have a particular name assigned to them." Gold, to take Hume's example, is nothing but the collection of the ideas of yellow, malleable, fusible, and so on. Even the mind, or the "self," is only a "heap or collection of different perceptions united together by certain relations and suppos'd tho' falsely, to be endow'd with a perfect simplicity or identity." This conclusion had important consequences for the problem of personal identity, to which Locke had devoted considerable attention. For if there is nothing to the mind but a collection of perceptions, then there is no self that perdures as the subject of these perceptions. Therefore, it does not make sense to speak of the subject of certain perceptions yesterday as the same self, or the same person, as the subject of certain perceptions today or in the future. There is no self or person there.

Immanuel Kant. Idealism is often defined as the view that everything that exists is mental—in other words, everything is either a mind or dependent for its existence on a mind. Kant was not strictly an idealist according to this definition. His doctrine of "transcendental idealism" held that all theoretical (*i.e.,* scientific) knowledge is a mix-

Transcendental idealism

ture of what is given in sense experience and what is contributed by the mind. The contributions of the mind are necessary conditions for having any sense experience at all. They include the spatial and temporal "forms" in which physical objects appear, as well as various extremely general features that together give the experience an intelligible structure. These features are imposed when the mind, in the act of forming a judgment about experience, brings the content of experience under one of the "pure concepts of the understanding." These concepts are unity, plurality, and totality; reality, negation, and limitation; inherence and subsistence, causality and dependence, and community (or reciprocity); and possibility, existence, and necessity. Among the more noteworthy of the mind's contributions to experience is causality, which Hume asserted has no real existence.

His idealism notwithstanding, Kant also believed that there exists a world independent of the mind and completely unknowable by it. This world consists of "things-in-themselves," which do not exist in space and time and do not enter into causal relations. Because of his commitment to realism, Kant was disturbed by Berkeley's uncompromising idealism, which amounted to a denial of the existence of the external world.

Because Kant's theory attributes to the mind many aspects of reality that earlier theories had assumed were given in or derived from experience, it can be thought of as inverting the traditional relation in epistemology between the mind and the world. According to Kant, knowledge results not when the mind accommodates itself to the world but rather when the world conforms to the requirements of human sensibility and rationality. Kant compared his reorientation of epistemology to the Copernican revolution in astronomy, which placed the Sun rather than the Earth at the centre of the universe.

According to Kant, the propositions that express human knowledge can be divided into three kinds: (1) analytic a priori propositions, such as "All bachelors are unmarried" and "All squares have four sides," (2) synthetic a posteriori propositions, such as "The cat is on the mat" and "It is raining," and (3) what he called "synthetic a priori" propositions, such as "Every event has a cause." Although in the last kind of proposition the meaning of the predicate term is not contained in the meaning of the subject term, it is nevertheless possible to know the proposition independently of experience, because it expresses a condition imposed by the forms of sensibility. Nothing can be an object of experience unless it is experienced as having causes and effects. Kant stated that the main purpose of his doctrine of transcendental idealism was to show how these synthetic a priori propositions are possible.

Synthetic a priori propositions

Because human beings can experience the world only as bounded by space and time and completely determined by causal laws, it follows that they can have no theoretical (*i.e.*, scientific) knowledge of anything that is inconsistent with such a realm or that by definition exists independently of it—this includes God, human freedom, and the immortality of the soul. Nevertheless, belief in these ideas is justified, according to Kant, because each is a necessary condition of our conceiving of ourselves as moral agents.

G.W.F. Hegel. The positive views of the German idealist philosopher Georg Wilhelm Friedrich Hegel (1770–1831) are notoriously difficult, and his epistemology is not susceptible of adequate summary within the scope of this article. Some of his criticisms of earlier epistemological views should be mentioned, however, since they helped to bring the modern era in philosophy to a close.

In his *Phenomenology of Spirit* (1807), Hegel criticized traditional empiricist epistemology for assuming that at least some of the sensory content of experience is simply "given" to the mind and apprehended directly as it is, without the mediation of concepts. According to Hegel, there is no such thing as direct apprehension, or unmediated knowledge. Although Kant also held that empirical knowledge necessarily involves concepts (as well as the mentally contributed forms of space and time), he nevertheless attributed too large a role to the given, according to Hegel.

Another mistake of earlier epistemological theories—both empiricist and rationalist—is the assumption that knowledge entails a kind of "correspondence" between belief and reality. The search for such a correspondence is logically absurd, Hegel argues, since every such search must end with some belief about whether or not the correspondence holds, in which case one has not advanced beyond belief. In other words, it is impossible to compare our beliefs with reality, because our experience of reality is always mediated by our beliefs. We cannot step outside belief altogether. For Hegel, the Kantian distinction between the phenomena of experience and the unknowable thing-in-itself is an instance of this absurdity. (A.P.Ma.)

CONTEMPORARY PHILOSOPHY

Contemporary philosophy begins in the late 19th and early 20th centuries. Much of what sets it off from modern philosophy is its explicit criticism of the modern tradition and sometimes its apparent indifference to it. There are two basic movements in contemporary philosophy: Continental philosophy, which is the philosophical style of philosophers in France, Germany, and other parts of continental western Europe, and analytic philosophy (also called Anglo-American philosophy), which includes the work of philosophers in Britain, the United States, and other parts of the English-speaking world.

Continental epistemology. In epistemology, Continental philosophers during the first quarter of the 20th century were preoccupied with the problem of overcoming the apparent gap between the knower and the known. If a human being has access only to his own ideas of the world and not to the world itself, how can there be knowledge at all?

The German philosopher Edmund Husserl (1859–1938) thought that the standard epistemological theories of his day lacked insight, because they did not focus on objects of knowledge as they are actually experienced by human beings. To emphasize the reorientation of thinking he advocated, he adopted the slogan, "To the things themselves." Philosophers needed to recover a sense of what is given in experience itself, and this could be accomplished only through a careful description of experiential phenomena. Thus, Husserl called his philosophy "phenomenology," which was to begin as a purely descriptive science and only later to ascend to a theoretical, or "transcendental," one.

Phenomenology

According to Husserl, the philosophies of Descartes and Kant presupposed a gap between the aspiring knower and what is known, one that made claims to knowledge of the external world dubious and in need of justification. These presuppositions violated Husserl's belief that philosophy, as the most fundamental science, should be free of presuppositions. Thus, he held that it is illegitimate to assume that there is a problem about our knowledge of the external world prior to conducting a completely presuppositionless investigation of the matter. The device that Husserl used to remove these presuppositions was the *epochē* (Greek: "withholding" or "suspension"), originally a principle of ancient Greek skepticism but in Husserl's philosophy a technique of "bracketing," or removing from consideration, not only all traditional philosophical theories but also all commonsensical beliefs so that pure phenomenological description can proceed.

The *epochē* was just one of a series of so-called transcendental reductions that Husserl proposed in order to ensure that he was not presupposing anything. One of these reductions supposedly gave one access to "the transcendental ego," or "pure consciousness." Although one might expect phenomenology then to describe the experience or contents of this ego, Husserl instead aimed at "eidetic reduction"—that is, the discovery of the essences of various sorts of ideas, such as redness, surface, or relation. All these moves were part of Husserl's project of discovering a perfect methodology for philosophy, one that would ensure absolute certainty.

Husserl's transcendental ego seemed very much like the Cartesian mind that thinks of a world but has neither direct access to nor certainty of it. Accordingly, Husserl attempted, in *Cartesian Meditations* (1931), to overcome the apparent gap between the ego and the world—the very thing he had set out to destroy or to bypass in earlier works. Because the transcendental ego seems to be the only

genuinely existent consciousness, Husserl also was faced with the task of overcoming the problem of solipsism.

Martin Heidegger

Many of Husserl's followers, including his most famous student, Martin Heidegger (1889–1976), recognized that something had gone radically wrong with the original direction of phenomenology. According to Heidegger's diagnosis, the root of the problem was Husserl's assumption that there is an "Archimedean point" of human knowledge. But there is no such ego detached from the world and filled with ideas or representations, according to Heidegger. In *Being and Time* (1927), Heidegger returned to the original formulation of the phenomenological project as a return to the things themselves. Thus, in Heidegger's approach, all transcendental reductions are abandoned. What he claimed to discover is that human beings are inherently world-bound. The world does not need to be derived; it is presupposed by human experience. In their prereflective experience, humans inhabit a sociocultural environment in which the primordial kind of cognition is practical and communal, not theoretical or individual ("egoistic"). Human beings interact with the things of their everyday world (*Lebenswelt*) as a workman interacts with his tools; they hardly ever approach the world as a philosopher or scientist would. The theoretical knowledge of a philosopher is a derivative and specialized form of cognition, and the major mistake of epistemology from Descartes to Kant to Husserl was to treat philosophical knowledge as a paradigm of all knowledge.

Notwithstanding Heidegger's insistence that a human being is something that inhabits a world, he marked out human reality as ontologically special. He called this reality *Dasein*—the being, apart from all others, that is "present" to the world. Thus, as for Husserl, a cognitive being takes pride of place in Heidegger's philosophy.

In France, the principal representative of phenomenology in the mid-century was Maurice Merleau-Ponty (1908–61). Merleau-Ponty rejected Husserl's bracketing of the world, arguing that human experience of the world is primary, a view he encapsulated in the phrase "the primacy of perception." He furthermore held that dualistic analyses of knowledge, best exemplified by traditional Cartesian mind-body dualism, are inadequate. In fact, no conceptualization of the world can be complete in his view. Because human cognitive experience requires a body and the body a position in space, human experience is necessarily perspectival and thus incomplete. Although humans experience material beings as multidimensional objects, part of the object always exceeds the cognitive grasp of the person, just because of his limited perspective. In *Phenomenology of Perception* (1945), Merleau-Ponty develops these ideas (along with a detailed attack on the sense-datum theory, discussed below).

The epistemological views of Jean-Paul Sartre (1905–80) are similar in some respects to those of Merleau-Ponty. Both philosophers reject Husserl's transcendental reductions, and both think of human reality as "being-in-the-world." But Sartre's views have Cartesian elements that were anathema to Merleau-Ponty. Sartre distinguished between two basic kinds of being. Being-in-itself (*en soi*) is the inert and determinate world of nonhuman existence. Over and against it is being-for-itself (*pour soi*), which is the pure consciousness that defines human reality.

The rejection of dualisms

Later Continental philosophers attacked the entire tradition from Descartes to the 20th century for its explicit or implicit dualisms. Being/nonbeing, mind/body, knower/known, ego/world, being-in-itself/being-for-itself are all variations of a pattern of thinking that the philosophers of the last third of the 20th century tried to undermine. The structuralist Michel Foucault (1926–84), for example, wrote extensive historical studies, most notably *The Archaeology of Knowledge* (1969), in an attempt to demonstrate that all concepts are historically conditioned and that many of the most important ones serve the political function of controlling people rather than any purely cognitive purpose. Jacques Derrida has claimed that all dualisms are value-laden and indefensible. His technique of deconstruction aimed to show that every philosophical dichotomy is incoherent, because whatever can be said about one term of the dichotomy can also be said of the other.

Dissatisfaction with the Cartesian philosophical tradition can also be found in the United States. The American pragmatist John Dewey (1859–1952) directly challenged the idea that knowledge is primarily theoretical; experience, he argued, consists of an interaction between a living being and his environment. Knowledge is not a fixed apprehension of something but a process of acting and being acted upon. Richard Rorty has done much to reconcile Continental and analytic philosophy. He has argued that Dewey, Heidegger, and Ludwig Wittgenstein are the three greatest philosophers of the 20th century, specifically because of their attacks on the epistemological tradition of modern philosophy.

(A.P.Ma.)

Analytic epistemology. Analytic philosophy, the prevailing philosophy in the Anglo-American world from the beginning of the 20th century, has its origins in symbolic logic (or formal logic) on the one hand and in British empiricism on the other. Some of its most important contributions have been made in areas other than epistemology, though its epistemological contributions also have been of the first order. Its main characteristics have been the avoidance of system building and a commitment to detailed, piecemeal analyses of specific issues. Within this tradition there have been two main approaches: a formal style deriving from logic and an informal style emphasizing ordinary language. Among those identified with the first method are Gottlob Frege (1848–1925), Bertrand Russell (1872–1970), Rudolf Carnap (1891–1970), Alfred Tarski (1902–83), and W.V.O. Quine (1908–2000); and among those identified with the second are G.E. Moore (1873–1958), Gilbert Ryle (1900–76), J.L. Austin (1911–60), Norman Malcolm (1911–90), P.F. Strawson, and Zeno Vendler. Ludwig Wittgenstein (1889–1951) can be situated in both groups, his early work, including the *Tractatus Logico-Philosophicus* (1921), belonging to the former tradition and his later work, including the posthumously published *Philosophical Investigations* (1953) and *On Certainty* (1969), to the latter.

Perhaps the most distinctive feature of analytic philosophy is its emphasis on the role that language plays in the creation and resolution of philosophical problems. These problems, it is said, arise through misunderstandings of the forms and uses of everyday language. Wittgenstein said in this connection: "Philosophy is a battle against the bewitchment of the intelligence by means of language." The adoption at the beginning of the 20th century of the idea that philosophical problems are in some important sense linguistic (or conceptual), a hallmark of the analytic approach, has been called the "linguistic turn."

Commonsense philosophy, logical positivism, and naturalized epistemology. Three of the most notable schools of thought in analytic philosophy are commonsense philosophy, logical positivism, and naturalized epistemology. Commonsense philosophy is the name given to the epistemological views of Moore, who attempted to defend what he called the "commonsense" view of the world against both skepticism and idealism. This view, according to Moore, comprises a number of propositions—such as the propositions that the Earth exists, that it is very old, and that other persons now exist on it—that virtually everybody knows with certainty to be true. Any philosophical theory that runs counter to the commonsense view, therefore, can be rejected out of hand as mistaken. Into this category fall all forms of skepticism and idealism. Wittgenstein also rejected skepticism and idealism, though for very different reasons. For him, these positions are based on simplistic misunderstandings of epistemic concepts, misunderstandings that arise from a failure to recognize the rich variety of ways in which epistemic language (including words like "belief," "knowledge," "certainty," "justification," and "doubt") is used in everyday situations. In *On Certainty,* Wittgenstein contrasted the concepts of certainty and knowledge, arguing that certainty is not a "surer" form of knowledge but the necessary backdrop against which the "language games" of knowing, doubting, and inquiring take place. As that which "stands fast for all of us," certitude is ultimately a kind of action: "Action lies at the bottom of the language game."

The doctrines associated with logical positivism (also

Logical positivism

called logical empiricism) were developed originally in the 1920s and '30s by a group of philosophers and scientists known as the Vienna Circle. Logical positivism became one of the dominant schools of philosophy in England with the publication in 1936 of *Language, Truth, and Logic,* by A.J. Ayer (1910–89). Among the most influential theses put forward by the logical positivists was the claim that in order for a proposition with empirical content—*i.e.,* one that purports to say something about the world—to be meaningful, or cognitively significant, it must be possible, at least in principle, to verify the proposition through experience. Since many of the utterances of traditional philosophy (especially metaphysical utterances, such as "God exists") are not empirically verifiable even in principle, they are, according to the logical positivists, literally nonsense. In their view, the only legitimate function of philosophy is conceptual analysis—*i.e.,* the logical clarification of concepts, especially those associated with natural science (*e.g.,* probability and causality).

In his 1950 essay "Two Dogmas of Empiricism," Quine launched an attack upon the traditional distinction between analytic statements, which were said to be true by virtue of the meanings of the terms they contain, and synthetic statements, which were supposed to be true (or false) by virtue of certain facts about the world. He argued powerfully that the difference is one of degree rather than kind. In a later work, *Word and Object* (1960), Quine developed a doctrine known as "naturalized epistemology." According to this view, epistemology has no normative function—*i.e.,* it does not tell us what we ought to believe; instead, its only legitimate role is to describe the way knowledge, and especially scientific knowledge, is actually obtained. In effect, its function is to describe how present science arrives at the beliefs accepted by the scientific community.

Perception and knowledge. The epistemological interests of analytic philosophers in the first half of the 20th century were largely focused on the relationship between knowledge and perception. The major figures in this period were Russell, Moore, H.H. Price (1899–1984), C.D. Broad (1887–1971), Ayer, and H. Paul Grice (1913–88). Although their views differed considerably, all were advocates of a general doctrine known as sense-data theory.

Sense-data theory

The technical term "sense-data" is sometimes explained by means of examples. If one is hallucinating and sees pink rats, one is having a certain visual sensation of rats of a certain colour, though there are no real rats present. The sensation is what is called a "sense-datum." The image one sees with one's eyes closed after looking fixedly at a bright light (an afterimage) is another example. Even in cases of normal vision, however, one can be said to be apprehending sense-data. For instance, when one looks at a round penny from a certain angle, the penny will seem to have an elliptical shape. In such a case, there is an elliptical sense-datum in one's visual field, though the penny itself continues to be round. This last example was held by Broad, Price, and Moore to be particularly important, for it seems to make a strong case for holding that one always perceives sense-data, whether one's perception is normal or not.

In each of these examples, according to defenders of sense-data theory, there is something of which one is "directly" aware, meaning that one's awareness of it is immediate and does not depend on any inference or judgment. A sense-datum is thus frequently defined as an object of direct perception. According to Broad, Price, and Ayer, sense-data differ from physical objects in that they always have the properties they appear to have—*i.e.,* they cannot appear to have properties they do not really have. The problem for the philosopher who accepts sense-data is then to show how, on the basis of these private sensations, one can be justified in believing that there are physical objects that exist independently of our perceptions. Russell in particular tried to show, in such works as *The Problems of Philosophy* (1912) and *Our Knowledge of the External World* (1914), that knowledge of the external world could be logically constructed out of sense-data.

Sense-data theory was criticized by proponents of the so-called theory of appearing, such as G.A. Paul and W.H.F. Barnes, who claimed that the arguments for their existence are invalid. From the fact that a penny looks elliptical from a certain perspective, they objected, it does not follow that there must exist a separate entity that has the property of being elliptical. To assume that it does is simply to misunderstand how common perceptual situations are described. The most powerful such attack on sense-data theory was presented by Austin in his posthumously published lectures *Sense and Sensibilia* (1962).

The theory of appearing was in turn rejected by many philosophers, who held that it failed to provide an adequate account of the epistemological status of illusions and other visual anomalies. The aim of these thinkers was to give a coherent account of how knowledge is possible given the existence of sense-data and the possibility of perceptual error. The two main types of theories they developed were realism and phenomenalism.

Realism. Realism is both an epistemological and a metaphysical doctrine. In its epistemological aspect, realism claims that at least some of the objects apprehended through perception are "public" rather than "private." In its metaphysical aspect, realism holds that at least some objects of perception exist independently of the mind. It is especially the second of these principles that distinguishes realists from phenomenalists.

Realists believe that an intuitive, commonsense distinction can be made between two classes of entities perceived by human beings. One class, typically called "mental," consists of things like headaches, thoughts, pains, and desires; the other class, typically called "physical," consists of things like tables, rocks, planets, persons, animals, and certain physical phenomena such as rainbows, lightning, and shadows. According to realist epistemology, mental entities are private, in the sense that each of them is apprehensible by one person only. Although more than one person can have a headache or feel pain, for example, no two people can have the very same headache or feel the very same pain. In contrast, physical objects are public—more than one person can see or touch the same chair.

Mental and physical objects

Realists also believe that, whereas physical objects are mind-independent, mental objects are not. To say that an object is mind-independent is just to say that its existence does not depend on its being perceived or experienced by anyone. Thus, whether or not a particular table is being seen or touched by someone has no effect upon its existence. Even if no one is perceiving it, it would still exist (other things being equal). But this is not true of the mental. According to realists, if no one is having a headache, then it does not make sense to say that a headache exists. A headache is thus mind-dependent in a way in which tables, rocks, and shadows are not.

Traditional realist theories of knowledge thus begin by assuming the public-private distinction, and most realists also assume that one does not have to prove the existence of mental phenomena. These are things of which each person is directly aware, and there is no special "problem" about their existence. But they do not assume this to be true of physical phenomena. As the existence of visual aberrations, illusions, and other anomalies shows, one cannot be sure that in any perceptual situation one is apprehending physical objects. All a person can be sure of is that he is aware of something, an appearance of some sort—say of a bent stick in water. Whether that appearance corresponds to anything actually existing in the external world is an open question.

In his work *Foundations of Empirical Knowledge* (1940), Ayer called this difficulty "the egocentric predicament." When a person looks at what he thinks is a physical object, such as a chair, what he is directly apprehending is a sense-datum, a certain visual appearance. But such an appearance seems to be private to that person; it seems to be something mental and not publicly accessible. What then justifies the individual's belief in the existence of supposedly external objects—*i.e.,* physical entities that are public and exist independently of the mind? Realists developed two main responses to this challenge: direct (or "naive") realism and representative realism, also called the "causal theory."

In contrast to traditional realism, direct realism holds that physical objects themselves are perceived "directly." That

Direct and representative realism

is, what one immediately perceives is the physical object itself (or a part of it); thus there is no problem about inferring the existence of such objects from the contents of one's perception. Some direct realists, such as Moore and his followers, continued to accept the existence of sense-data, but unlike traditional realists they held that, rather than mental entities, sense-data might be physical parts of the surface of the perceived object itself. Other direct realists, such as the perceptual psychologist James J. Gibson (1904–79), rejected sense-data theory altogether, claiming that the surfaces of physical objects are normally directly observed. Thompson Clarke went beyond Moore in arguing that normally the entire physical object, rather than only its surface, is perceived directly.

All these views have trouble explaining perceptual anomalies. Indeed, it was because of such difficulties that Moore, in his last published paper, "Visual Sense-Data" (1957), abandoned direct realism. He held that, because the elliptical sense-datum one perceives when one looks at a round coin cannot be identical with the coin's circular surface, one cannot be seeing the coin directly. Hence, one cannot have direct knowledge of physical objects.

Although developed in response to the failure of direct realism, the theory of representative realism is in essence an old view; its best-known exponent in modern philosophy was Locke. It is also sometimes called "the scientific theory," because it seems to be supported by findings in optics and physics. Like most forms of realism, representative realism holds that the direct objects of perception are sense-data (or their equivalents). What it adds is a scientifically grounded causal account of the origin of sense-data in the stimulation of sense organs and the operation of the central nervous system. Thus the theory would explain visual sense-data as follows. Light is reflected from an opaque surface, traverses an intervening space, and, if certain standard conditions are met, strikes the retina, where it activates a series of nerve cells, including the rods and cones, the bipolar cells, and the ganglion cells of the optic nerve, eventually resulting in an event in the brain consisting of the experience of a visual sense-datum—*i.e.,* "seeing."

Given an appropriate normal causal connection between the original external object and the sense-datum, representative realists assert that the sense-datum will accurately represent the object as it really is. Visual illusion is explained in various ways, but usually as the result of some anomaly in the causal chain that gives rise to distortions and other types of aberrant visual phenomena.

Representative realism is thus a theory of indirect perception, because it holds that human observers are directly aware of sense-data and only indirectly aware of the physical objects that cause these data in the brain. The difficulty with this view is that, since one cannot compare the sense-datum that is directly perceived with the original object, one can never be sure that it gives an accurate representation of it; and therefore human beings cannot know that the real world corresponds to their perceptions. They are still confined within the circle of appearance after all. It thus seems that neither version of realism satisfactorily solves the problem with which it began.

Phenomenalism. In light of the difficulties faced by realist theories of perception some philosophers, so-called phenomenalists, proposed a completely different way of analyzing the relationship between perception and knowledge. In particular, they rejected the distinction between independently existing physical objects and mind-dependent sense-data. They claimed that either the very notion of independent existence is nonsense because human beings have no evidence for it, or what is meant by "independent existence" must be understood in such a way as not to go beyond the sort of perceptual evidence human beings do or could have for the existence of such things. In effect, these philosophers challenged the cogency of the intuitive ideas that the ordinary person supposedly has about independent existence.

The notion of independent existence

All variants of phenomenalism are strongly "verificationist." That is, they wish to maintain that claims about the purported external world must be capable of verification, or confirmation. This entails that no such claim can assert the existence of, or otherwise make reference to, anything that is beyond the realm of possible perceptual experience.

Phenomenalists have thus tried to analyze in wholly perceptual terms what it means to say that a particular object—say a tomato—exists. Any such analysis, they claim, must begin by deciding what sort of an object a tomato is. In their view, a tomato is first of all something that has certain perceptible properties, including a certain size, weight, colour, and shape. If one were to abstract the set of all such properties from the object, however, nothing would be left over—there would be no presumed Lockean "substratum" that supports these properties and that itself is unperceived. There is thus no evidence in favour of such an unperceivable feature, and no reference to it is needed in explaining what a tomato or any so-called physical object is.

To talk about any existent object is thus to talk about a collection of perceivable features localized in a particular portion of space-time. Accordingly, to say that a tomato exists is to describe either a collection of properties that an observer is actually perceiving or a collection that such an observer would perceive under certain specified conditions. To say, for instance, that a tomato exists in the next room is to say that, if one went into that room, one would see a familiar reddish shape, one would obtain a certain taste if one bit into it, and one would feel something soft and smooth if one touched it. To speak about the tomato's existing unperceived in the next room thus does not entail that it is unperceivable. In principle, everything that exists is perceivable. Therefore, the notion of existing independently of perception has been misunderstood or mischaracterized by both philosophers and nonphilosophers. Once it is understood that objects are merely sets of properties and that such properties are in principle always perceivable, the notion that there is some sort of unbridgeable gap between people's perceptions and the objects they perceive is seen to be just a mistake.

The criterion of coherence

In this view, perceptual error is explained in terms of coherence and predictability. To say with truth that one is perceiving a tomato means that one's present set of perceptual experiences and an unspecified set of future experiences will "cohere" in certain ways. That is, if the object a person is looking at is a tomato, then he can expect that, if he touches, tastes, and smells it, he will experience a recognizable grouping of sensations. If the object he has in his visual field is hallucinatory, then there will be a lack of coherence between what he touches, tastes, and smells. He might, for example, see a red shape but not be able to touch or taste anything.

The theory is generalized to include what others would touch, see, and hear as well, so that what the realists call "public" will also be defined in terms of the coherence of perceptions. A so-called physical object is public if the perceptions of many persons cohere or agree; otherwise it is not. This explains why a headache is not a public object. In similar fashion, a so-called physical object will be said to have an independent existence if expectations of future perceptual experiences are borne out. If tomorrow, or the day after, a person has perceptual experiences similar to those he had today, then he can say that the object he is perceiving has an independent existence. The phenomenalist thus attempts to account for all the facts that the realist wishes to explain without positing the existence of anything that transcends possible experience.

Criticisms of this view have tended to be technical. Generally speaking, however, realists have objected to it on the ground that it is counterintuitive to think of physical objects like tomatoes as being sets of actual or possible perceptual experiences. The realist argues that human beings do have such experiences, or under certain circumstances would have them, because there is an object out there that exists independently of them and is their source. Phenomenalism, they contend, implies that, if no perceivers existed, then the world would contain no objects, and this is surely inconsistent both with what ordinary persons believe and with the known scientific fact that all sorts of objects existed in the universe long before there were any perceivers. But supporters deny that phenomenalism carries such an implication, and the debate about its merits remains unresolved.

Analytic epistemology today. In the last quarter of the

20th century, important contributions to epistemology were made by researchers in neuroscience, psychology, artificial intelligence, computer science. These investigations produced insights into the nature of vision, the formation of mental representations of the external world, and the storage and retrieval of information in memory, among many other processes. The new approaches in effect revived indirect theories of perception that emphasized the subjective experience of the observer. Indeed, many of them made use of concepts—such as "qualia," and "felt sensation"—that were essentially equivalent to the notion of sense-data.

New support for skepticism

Some of the new approaches also seemed to lend support to skeptical conclusions of the sort that early sense-data theorists had attempted to overcome. The neurologist Richard Gregory, for example, argued in 1993 that no theory of direct perception, such as that proposed by Gibson, could be supported, given "the indirectness imposed by the many physiological steps or stages of visual and other sensory perception. . . . For these and other reasons we may safely abandon direct accounts of perception in favor of indirectly related and never certain . . . hypotheses of reality." Similarly, work by another neurologist, Vilayanur Ramachandran, showed that the stimulation of certain areas of the brain in normal people produces sensations comparable to those felt in so-called "phantom limb" phenomena (the experience by an amputee of pains or other sensations that seem to be located in a missing limb). The conclusion that Ramachandran drew from his work is a modern variation of Descartes's "evil genius" hypothesis: that we can never be certain that the sensations we experience accurately reflect an external reality.

On the basis of experimental findings such as these, many philosophers adopted forms of radical skepticism. Benson Mates, for example, declared: "Ultimately the only basis I can have for a claim to know that there exists something other than my own perceptions is the nature of those very perceptions. But they could be just as they are even if there did not exist anything else. Ergo, I have no basis for the knowledge-claim in question." Mates concluded, following Sextus Empiricus, that human beings cannot make any justifiable assertions about anything other than their own sense experiences.

Philosophers have responded to these challenges in a variety of ways. Avrum Stroll, for example, has argued that the views of skeptics such as Mates, as well those of many other modern proponents of indirect perception, rest on a conceptual mistake: the failure to distinguish between scientific and philosophical accounts of the connection between sense experience and objects in the external world. In the case of vision, the scientific account (or, as he calls it, the "causal story") describes the familiar sequence of events that occurs according to well-known optical and physical laws. Citing this account, proponents of indirect perception point out that every event in such a causal sequence effects some modification of the input received from the preceding event. Thus, the light energy that strikes the retina is converted to electrochemical energy by the rods and cones, among other nerve cells, and the electrical impulses transmitted along the nervous pathways leading to the brain are reorganized in important ways at every synapse. From the fact that the input to every event in the sequence undergoes some modification, it follows that the end result of the process, the visual representation of the external object, must differ considerably from the elements of the original input, including the object itself. From this observation, theorists of indirect perception who are inclined toward skepticism conclude that one cannot be certain that the sensation one experiences in seeing a particular object represents the object as it really is.

But this last inference is unwarranted, according to Stroll. What the argument shows is only that the visual representation of the object and the object itself are different (a fact that hardly needs pointing out); it does not show that we cannot be certain whether the representation is accurate. Indeed, a strong argument can be made to show that our perceptual experiences cannot all be inaccurate. For if they were, then it would be impossible to compare any given perception with its object in order to determine whether the sensation represented the object accurately. But in that case, it also would be impossible to verify the claim that all our perceptions are inaccurate. Hence, the claim that all our perceptions are inaccurate is scientifically untestable. According to Stroll, this is a decisive objection against the skeptical position.

The implications of these developments in the cognitive sciences are clearly important for epistemology. The experimental evidence adduced for indirect perception has raised philosophical discussion of the nature of human perception to a new level. It is clear that a serious debate has begun, and at this point it is impossible to predict its outcome. (Av.S.)

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Erasmus

Born in Rotterdam in 1469, Desiderius Erasmus was the greatest European scholar of the 16th century. Using the philological methods pioneered by Italian humanists, he helped lay the groundwork for the historical-critical study of the past, especially in his studies of the Greek New Testament and the Church Fathers. His educational writings contributed to the replacement of the older scholastic curriculum by the new humanist emphasis on the classics. By criticizing ecclesiastical abuses, while pointing to a better age in the distant past, he encouraged the growing urge for reform, which found expression both in the Protestant Reformation and in the Catholic Counter-Reformation. Finally, his independent stance in an age of fierce confessional controversy—rejecting both Luther's doctrine of predestination and the powers that were claimed for the papacy—made him a target of suspicion for loyal partisans on both sides and a beacon for those who valued liberty more than orthodoxy.

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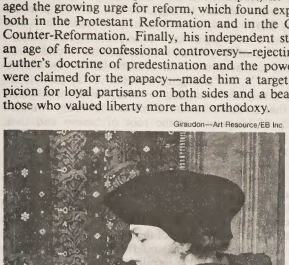

Erasmus, oil painting by Hans Holbein the Younger, 1523. In the Louvre, Paris.

Early life and career. Erasmus was the second illegitimate son of Roger Gerard, a priest, and Margaret, a physician's daughter. He advanced as far as the third-highest class at the chapter school of St. Lebuin's in Deventer. One of his teachers, Jan Synthen, was a humanist, as was the headmaster, Alexander Hegius. The schoolboy Erasmus was clever enough to write classical Latin verse that impresses a modern reader as cosmopolitan.

School years

After both parents died, the guardians of the two boys sent them to a school in 's Hertogenbosch conducted by the Brethren of the Common Life, a lay religious movement that fostered monastic vocations. Erasmus would remember this school only for a severe discipline intended, he said, to teach humility by breaking a boy's spirit.

Having little other choice, both brothers entered monasteries. Erasmus chose the Augustinian canons regular at Steyn, near Gouda, where he seems to have remained about seven years (1485–92). While at Steyn he paraphrased Lorenzo Valla's *Elegantiae,* which was both a compendium of pure classical usage and a manifesto against the scholastic "barbarians" who had allegedly corrupted it. Erasmus' monastic superiors became "barbarians" for him by discouraging his classical studies. Thus, after his ordination to the priesthood (April 1492), he was happy to escape the monastery by accepting a post as Latin secretary to the influential Henry of Bergen, bishop of Cambrai. His *Antibarbarorum liber,* extant from a revision of 1494–95, is a vigorous restatement of patristic arguments for the utility of the pagan classics, with a polemical thrust against the cloister he had left behind: "All sound learning is secular learning."

Erasmus was not suited to a courtier's life, nor did things improve much when the bishop was induced to send him to the University of Paris to study theology (1495). He disliked the quasi-monastic regimen of the Collège de Montaigu, where he lodged initially, and pictured himself to a friend as sitting "with wrinkled brow and glazed eye" through Scotist lectures. To support his classical studies, he began taking in pupils; from this period (1497–1500) date the earliest versions of those aids to elegant Latin—including the *Colloquia* and the *Adagia*—that before long would be in use in humanist schools throughout Europe.

Thomas More and John Colet

The wandering scholar. In 1499 a pupil, William Blount, Lord Mountjoy, invited Erasmus to England. There he met Thomas More, who became a friend for life. John Colet quickened Erasmus' ambition to be a "primitive theologian," one who would expound Scripture not in the argumentative manner of the scholastics but in the manner of Jerome and the other Church Fathers, who lived in an age when men still understood and practiced the classical art of rhetoric. The impassioned Colet besought him to lecture on the Old Testament at Oxford, but the more cautious Erasmus was not ready. He returned to the Continent with a Latin copy of St. Paul's Epistles and the conviction that "ancient theology" required mastery of Greek.

On a visit to Artois, Fr. (1501), Erasmus met the fiery preacher Jean Voirier, who, though a Franciscan, told him that "monasticism was a life more of fatuous men than of religious men." Admirers recounted how Voirier's disciples faced death serenely, trusting in God, without the solemn reassurance of the last rites. Voirier lent Erasmus a copy of works by Origen, the early Greek Christian writer who promoted the allegorical, spiritualizing mode of scriptural interpretation, which had roots in Platonic philosophy. By 1502 Erasmus had settled in the university town of Louvain (Brabant) and was reading Origen and St. Paul in Greek. The fruit of his labours was *Enchiridion militis Christiani* (1503/04; *Handbook of a Christian Knight*). In this work Erasmus urged readers to "inject into the vitals" the teachings of Christ by studying and meditating on the Scriptures, using the spiritual interpretation favoured by the "ancients" to make the text pertinent to moral concerns. The *Enchiridion* was a manifesto of lay piety in its assertion that "monasticism is not piety." Erasmus' vocation as a "primitive theologian" was further developed through his discovery at Park Abbey, near Louvain, of a manuscript of Valla's *Adnotationes* on the Greek New Testament, which he published in 1505 with a dedication to Colet.

Travels to Italy

Erasmus sailed for England in 1505, hoping to find support for his studies. Instead he found an opportunity to travel to Italy, the land of promise for northern humanists, as tutor to the sons of the future Henry VIII's physician. The party arrived in the university town of Bologna in time to witness the triumphal entry (1506) of the warrior pope Julius II at the head of a conquering army, a scene that figures later in Erasmus' anonymously published satiric dialogue, *Julius exclusus e coelis* (written 1513–14). In Venice Erasmus was welcomed at the celebrated printing house of Aldus Manutius, where Byzantine émigrés enriched the intellectual life of a numerous scholarly company. For the Aldine press Erasmus expanded his *Adagia,* or annotated collection of Greek and Latin adages, into a

monument of erudition with over 3,000 entries; this was the book that first made him famous. The adage "Dutch ear" (*auris Batava*) is one of many hints that he was not an uncritical admirer of sophisticated Italy, with its theatrical sermons and its scholars who doubted the immortality of the soul; his aim was to write for honest and unassuming "Dutch ears."

De pueris instituendis, written in Italy though not published until 1529, is the clearest statement of Erasmus' enormous faith in the power of education. With strenuous effort the very stuff of human nature could be molded, so as to draw out (*e-ducare*) peaceful and social dispositions while discouraging unworthy appetites. Erasmus, it would almost be true to say, believed that one is what one reads. Thus the "humane letters" of classical and Christian antiquity would have a beneficent effect on the mind, in contrast to the disputatious temper induced by scholastic logic-chopping or the vengeful amour propre bred into young aristocrats by chivalric literature, "the stupid and tyrannical fables of King Arthur."

The celebrated *Moriae encomium,* or *Praise of Folly,* conceived as Erasmus crossed the Alps on his way back to England and written at Thomas More's house, expresses a very different mood. For the first time the earnest scholar saw his own efforts along with everyone else's as bathed in a universal irony, in which foolish passion carried the day: "Even the wise man must play the fool if he wishes to beget a child."

Little is known of Erasmus' long stay in England (1509–14), except that he lectured at Cambridge and worked on scholarly projects, including the Greek text of the New Testament. His later willingness to speak out as he did may have owed something to the courage of Colet, who risked royal disfavour by preaching a sermon against war at the court just as Henry VIII was looking for a good war in which to win his spurs. Having returned to the Continent, Erasmus made connections with the printing firm of Johann Froben and traveled to Basel to prepare a new edition of the *Adagia* (1515). In this and other works of about the same time Erasmus showed a new boldness in commenting on the ills of Christian society—popes who in their warlike ambition imitated Caesar rather than Christ; princes who hauled whole nations into war to avenge a personal slight; and preachers who looked to their own interests by pronouncing the princes' wars just or by nurturing superstitious observances among the faithful. To remedy these evils Erasmus looked to education. In particular, the training of preachers should be based on "the philosophy of Christ" rather than on scholastic methods. Erasmus tried to show the way with his annotated text of the Greek New Testament and his edition of St. Jerome's *Opera omnia,* both of which appeared from the Froben press in 1516. These were the months in which Erasmus thought he saw "the world growing young again," and the full measure of his optimism is expressed in one of the prefatory writings to the New Testament: "If the Gospel were truly preached, the Christian people would be spared many wars."

The function of education

Erasmus' home base was now in Brabant, where he had influential friends at the Habsburg court of the Netherlands in Brussels, notably the grand chancellor, Jean Sauvage. Through Sauvage he was named honorary councillor to the 16-year-old archduke Charles, the future Charles V, and was commissioned to write *Institutio principis Christiani* (1516; *The Education of a Christian Prince*) and *Querela pacis* (1517; *The Complaint of Peace*). These works expressed Erasmus' own convictions, but they also did no harm to Sauvage's faction at court, which wanted to maintain peace with France. It was at this time too that he began his *Paraphrases* of the books of the New Testament, each one dedicated to a monarch or a prince of the church. He was accepted as a member of the theology faculty at nearby Louvain, and he also took keen interest in a newly founded Trilingual College, with endowed chairs in Latin, Greek, and Hebrew. *Ratio verae theologiae* (1518) provided the rationale for the new theological education based on the study of languages. Revision of his Greek New Testament, especially of the copious annotations, began almost as soon as the first edition appeared. Though Erasmus certainly made mistakes as a textual critic, in the history of scholarship he is a towering figure, intuiting philological principles that in some cases would not be formulated explicitly until 150 years after his death. But conservative theologians at Louvain and elsewhere, mostly ignorant of Greek, were not willing to abandon the interpretation of Scripture to upstart "grammarians," nor did the atmosphere at Louvain improve when the second edition of Erasmus' New Testament (1519) replaced the Vulgate with his own Latin translation.

The Protestant challenge. From the very beginning of the momentous events sparked by Martin Luther's challenge to papal authority, Erasmus' clerical foes blamed him for inspiring Luther, just as some of Luther's admirers in Germany found that he merely proclaimed boldly what Erasmus had been hinting. In fact, Luther's first letter to Erasmus (1516) showed an important disagreement over the interpretation of St. Paul, and in 1518 Erasmus privately instructed his printer, Froben, to stop printing works by Luther, lest the two causes be confused. As he read Luther's writings, at least those prior to *The Babylonian Captivity of the Church* (1520), Erasmus found much to admire, and he could even describe Luther, in a letter to Pope Leo X, as "a mighty trumpet of Gospel truth." Being of a suspicious nature, however, he also convinced himself that Luther's fiercest enemies were men who saw the study of languages as the root of heresy and thus wanted to be rid of both at once. Hence he tugged at the slender threads of his influence, vainly hoping to forestall a confrontation that could only be destructive to "good letters." When he quit Brabant for Basel (December 1521), he did so lest he be faced with a personal request from the Emperor to write a book against Luther, which he could not have refused.

Erasmus and Luther

Erasmus' belief in the unity of the church was fundamental, but, like the Hollanders and Brabanters with whom he was most at home, he recoiled from the cruel logic of religious persecution. He expressed his views indirectly through the *Colloquia,* which had started as schoolboy dialogues but now became a vehicle for commentary. For example, in the colloquy "Inquisitio de fide" (1522) a Catholic finds to his surprise that Lutherans accept all the dogmas of the faith, that is, the articles of the Apostles' Creed. The implication is that bitter disputes like those over papal infallibility or Luther's doctrine of predestination are differences over mere opinion, not over dogmas binding on all the faithful. For Erasmus the root of the schism was not theology but anticlericalism and lay resentment of the laws and "ceremonies" that the clergy made binding under pain of hell. As he wrote privately to the Netherlandish pope Adrian VI (1522–23), whom he had known at Louvain, there was still hope of reconciliation, if only the church would ease the burden; this could be accomplished, for instance, by granting the chalice to the laity and by permitting priests to marry: "At the sweet name of liberty all things will revive."

When Adrian VI was succeeded by Clement VII, Erasmus could no longer avoid "descending into the arena" of theological combat, though he promised the Swiss reformer Huldrych Zwingli that he would attack Luther in a way that would not please the "pharisees." *De libero arbitrio* (1524) defended the place of human free choice in the process of salvation and argued that the consensus of the church through the ages is authoritative in the interpretation of Scripture. In reply Luther wrote one of his most important theological works, *De servo arbitrio* (1525), to which Erasmus responded with a lengthy, two-part *Hyperaspistes* (1526–27). In this controversy Erasmus lets it be seen that he would like to claim more for free will than St. Paul and St. Augustine seem to allow.

Controversy over free will

The years in Basel (1522–29) were filled with polemics, some of them rather tiresome by comparison to the great debate with Luther. Irritated by Protestants who called him a traitor to the Gospel as well as by hyper-orthodox Catholic theologians who repeatedly denounced him, Erasmus showed the petty side of his own nature often enough. Although there is material in his apologetic writings that scholars have yet to exploit, there seems no doubt that on the whole he was better at satiric barbs, such as the

colloquy representing one young "Pseudo-Evangelical" of his acquaintance as thwacking people over the head with a Gospel book to gain converts. Meanwhile he kept at work on the Greek New Testament (there would be five editions in all), the *Paraphrases,* and his editions of the Church Fathers, including Cyprian, Hilary, and Origen. He also took time to chastise those humanists, mostly Italian, who from a "superstitious" zeal for linguistic purity refused to sully their Latin prose with nonclassical terms (*Ciceronianus,* 1528).

Final years. In 1529, when Protestant Basel banned Catholic worship altogether, Erasmus and some of his humanist friends moved to the Catholic university town of Freiburg im Breisgau. He refused an invitation to the Diet of Augsburg, where Philipp Melanchthon's Augsburg Confession was to initiate the first meaningful discussions between Lutheran and Catholic theologians. He nonetheless encouraged such discussion in *De sarcienda ecclesiae concordia* (1533), which suggested that differences on the crucial doctrine of justification might be reconciled by considering a *duplex justitia,* the meaning of which he did not elaborate. Having returned to Basel to see his manual on preaching (*Ecclesiastes,* 1535) through the press, he lingered on in a city he found congenial; it was there he died on July 12, 1536. Like the disciples of Voirier, he seems not to have asked for the last sacraments of the church. His last words were in Dutch: "*Lieve God*" ("dear God").

Influence and achievement. Always the scholar, Erasmus could see many sides of an issue. But his hesitations and studied ambiguities were appreciated less and less in the generations that followed his death, as men girded for combat, theological or otherwise, in the service of their beliefs. For a time, while peacemakers on both sides had an opportunity to pursue meaningful discussions between Catholics and Lutherans, some of Erasmus' practical suggestions and his moderate theological views were directly pertinent. Even after ecumenism dwindled to a mere wisp of possibility, there were a few men willing to make themselves heirs of Erasmus' lonely struggle for a middle ground, like Jacques-Auguste de Thou in France and Hugo Grotius in the Netherlands; significantly, both were strong supporters of state authority and hoped to limit the influence of the clergy of their respective established churches. This tradition was perhaps strongest in the Netherlands, where Dirck Volckertszoon Coornhert and others found support in Erasmus for their advocacy of limited toleration for religious dissenters. Meanwhile, however, the Council of Trent and the rise of Calvinism ensured that such views were generally of marginal influence. The Catholic *index expurgatorius* of 1571 contained a long list of suspect passages to be deleted from any future editions of Erasmus' writings, and those Protestant tendencies that bear some comparison to Erasmus' defense of free will—current among the Philippists in Germany and the Arminians in the Netherlands—were bested by defenders of a sterner orthodoxy. Even in the classroom, Erasmus' preference for putting students directly in contact with the classics gave way to the use of compendiums and manuals of humanist rhetoric and logic that resembled nothing so much as the scholastic curriculum of the past. Similarly, the bold and independent scholarly temper with which Erasmus approached the text of the New Testament was for a long time submerged by the exigencies of theological polemics.

Erasmus' reputation began to improve in the late 17th century, when the last of Europe's religious wars was fading into memory and scholars like Richard Simon and Jean Le Clercq (the editor of Erasmus' works) were once again taking a more critical approach to biblical texts. By Voltaire's time, in the 18th century, it was possible to imagine that the clever and rather skeptical Erasmus must have been a philosophe before his time, one whose professions of religious devotion and submission to church authority could be seen as convenient evasions. This view of Erasmus, curiously parallel to the strictures of his orthodox critics, was long influential. Only in the past several decades have scholars given due recognition to the fact that the goal of his work was a Christianity purified by a deeper knowledge of its historic roots. Yet it was not entirely wrong to compare Erasmus with those Enlightenment thinkers who, like Voltaire, defended individual liberty at every turn and had little good to say about the various corporate solidarities by which human society holds together. Some historians would now trace the enduring debate between these complementary aspects of Western thought as far back as the 12th century, and in this very broad sense Erasmus and Voltaire are on the same side of a divide, just as, for instance, Machiavelli and Rousseau are on the other. In a unique manner that fused his multiple identities—as Netherlander, Renaissance humanist, and pre-Tridentine Catholic—Erasmus helped to build what may be called the liberal tradition of European culture.

MAJOR WORKS

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(J.D.T.)

Ethics

How should we live? Shall we aim at happiness or at knowledge, virtue, or the creation of beautiful objects? If we choose happiness, will it be our own or the happiness of all? And what of the more particular questions that face us: Is it right to be dishonest in a good cause? Can we justify living in opulence while elsewhere in the world people are starving? If conscripted to fight in a war we do not support, should we disobey the law? What are our obligations to the other creatures with whom we share this planet and to the generations of humans who will come after us?

Ethics deals with such questions at all levels. Its subject consists of the fundamental issues of practical decision making, and its major concerns include the nature of ultimate value and the standards by which human actions can be judged right or wrong.

The terms ethics and morality are closely related. We now often refer to ethical judgments or ethical principles where it once would have been more common to speak of moral judgments or moral principles. These applications are an extension of the meaning of ethics. Strictly speaking, however, the term refers not to morality itself but to the field of study, or branch of inquiry, that has morality as its subject matter. In this sense, ethics is equivalent to moral philosophy.

Although ethics has always been viewed as a branch of philosophy, its all-embracing practical nature links it with many other areas of study, including anthropology, biology, economics, history, politics, sociology, and theology. Yet, ethics remains distinct from such disciplines because it is not a matter of factual knowledge in the way that the sciences and other branches of inquiry are. Rather, it has to do with determining the nature of normative theories and applying these sets of principles to practical moral problems.

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The origins of ethics

MYTHICAL ACCOUNTS

When did ethics begin and how did it originate? If we are referring to ethics proper—*i.e.*, the systematic study of what we ought to do—it is clear that ethics can only have come into existence when human beings started to reflect on the best way to live. This reflective stage emerged long after human societies had developed some kind of morality, usually in the form of customary standards of right and wrong conduct. The process of reflection tended to arise from such customs, even if in the end it may have found them wanting. Accordingly, ethics began with the introduction of the first moral codes.

Virtually every human society has some form of myth to explain the origin of morality. In the Louvre in Paris there is a black Babylonian column with a relief showing the sun god Shamash presenting the code of laws to Hammurabi. The Old Testament account of God giving the Ten Commandments to Moses on Mt. Sinai might be considered another example. In Plato's *Protagoras* there is an avowedly mythical account of how Zeus took pity on the hapless humans, who, living in small groups and with inadequate teeth, weak claws, and lack of speed, were no match for the other beasts. To make up for these deficiencies, Zeus gave humans a moral sense and the capacity for law and justice, so that they could live in larger communities and cooperate with one another.

Notion of divine origin

That morality should be invested with all the mystery and power of divine origin is not surprising. Nothing else could provide such strong reasons for accepting the moral law. By attributing a divine origin to morality, the priesthood became its interpreter and guardian, and thereby secured for itself a power that it would not readily relinquish. This link between morality and religion has been so firmly forged that it is still sometimes asserted that there

can be no morality without religion. According to this view, ethics ceases to be an independent field of study. It becomes, instead, moral theology.

There is some difficulty, already known to Plato, with the view that morality was created by a divine power. In his dialogue *Euthyphro,* Plato considered the suggestion that it is divine approval that makes an action good. Plato pointed out that if this were the case, we could not say that the gods approve of the actions because the actions are good. Why then do the gods approve of these actions rather than others? Is their approval entirely arbitrary? Plato considered this impossible and so held that there must be some standards of right or wrong that are independent of the likes and dislikes of the gods. Modern philosophers have generally accepted Plato's argument because the alternative implies that if the gods had happened to approve of torturing children and to disapprove of helping one's neighbours, then torture would have been good and neighbourliness bad.

A modern theist might say that since God is good, he could not possibly approve of torturing children nor disapprove of helping neighbours. In saying this, however, the theist would have tacitly admitted that there is a standard of goodness that is independent of God. Without an independent standard, it would be pointless to say that God is good; this could only mean that God is approved of by God. It seems therefore that, even for those who believe in the existence of God, it is impossible to give a satisfactory account of the origin of morality in terms of a divine creation. We need a different account.

There are other possible connections between religion and morality. It has been said that even if good and evil exist independently of God or the gods, only divine revelation can reliably inform us about good and evil. An obvious problem with this view is that those who receive divine revelations, or who consider themselves qualified to interpret them, do not always agree on what is good and what is evil. Without an accepted criterion for the authenticity of a revelation or an interpretation, we are no better off, so far as reaching moral agreement is concerned, than we would be if we were to decide on good and evil ourselves with no assistance from religion.

Traditionally, a more important link between religion and ethics was that religious teachings were thought to provide a reason for doing what is right. In its crudest form, the reason was that those who obey the moral law will be rewarded by an eternity of bliss while everyone else roasts in hell. In more sophisticated versions, the motivation provided by religion was less blatantly self-seeking and more of an inspirational kind. Whether in its crude or sophisticated version, or something in between, religion does provide an answer to one of the great questions of ethics: Why should I do what is right? As will be seen in the course of this article, however, the answer provided by religion is by no means the only answer. It will be considered after the alternatives have been examined.

PREHUMAN ETHICS

Can we do better than the religious accounts of the origin of morality? Because, for obvious reasons, we have no historical record of a human society in the period before it had any standards of right and wrong, history cannot tell us the origins of morality. Nor is anthropology able to assist because all human societies studied have already had, except perhaps during the most extreme circumstances, their own form of morality. Fortunately there is another mode of inquiry open to us. Human beings are social animals. Living in a social group is a characteristic we share with many other animal species, including our closest relatives, the apes. Presumably, the common ancestor of humans and apes also lived in a social group, so that we were social beings before we were human beings. Here, then, in the social behaviour of nonhuman animals and in the evolutionary theory that explains such behaviour, we may find the origins of human morality.

Social life, even for nonhuman animals, requires constraints on behaviour. No group can stay together if its members make frequent, no-holds-barred attacks on one another. Social animals either refrain altogether from attacking other members of the social group, or, if an attack does take place, the ensuing struggle does not become a fight to the death—it is over when the weaker animal shows submissive behaviour. It is not difficult to see analogies here with human moral codes. The parallels, however, go much further than this. Like humans, social animals may behave in ways that benefit other members of the group at some cost or risk to themselves. Male baboons threaten predators and cover the rear as the troop retreats. Wolves and wild dogs bring meat back to members of the pack not present at the kill. Gibbons and chimpanzees with food will, in response to a gesture, share their food with others of the group. Dolphins support sick or injured animals, swimming under them for hours at a time and pushing them to the surface so they can breathe.

Apparent altruistic behaviour among nonhuman animals

It may be thought that the existence of such apparently altruistic behaviour is odd, for evolutionary theory states that those who do not struggle to survive and reproduce will be wiped out in the ruthless competition known as natural selection. Research in evolutionary theory applied to social behaviour, however, has shown that evolution need not be quite so ruthless after all. Some of this altruistic behaviour is explained by kin selection. The most obvious examples are those in which parents make sacrifices for their offspring. If wolves help their cubs to survive, it is more likely that genetic characteristics, including the characteristic of helping their own cubs, will spread through further generations of wolves.

Less obviously, the principle also holds for assistance to other close relatives, even if they are not descendants. A child shares 50 percent of the genes of each of its parents, but full siblings too, on the average, have 50 percent of their genes in common. Thus a tendency to sacrifice one's life for two or more of one's siblings could spread from one generation to the next. Between cousins, where only 12½ percent of the genes are shared, the sacrifice-to-benefit ratio would have to be correspondingly increased.

When apparent altruism is not between kin, it may be based on reciprocity. A monkey will present its back to another monkey, who will pick out parasites; after a time the roles will be reversed. Reciprocity may also be a factor in food sharing among unrelated animals. Such reciprocity will pay off, in evolutionary terms, as long as the costs of helping are less than the benefits of being helped and as long as animals will not gain in the long run by "cheating"—that is to say, by receiving favours without returning them. It would seem that the best way to ensure that those who cheat do not prosper is for animals to be able to recognize cheats and refuse them the benefits of cooperation the next time around. This is only possible among intelligent animals living in small, stable groups over a long period of time. Evidence supports this conclusion: reciprocal behaviour has been observed in birds and mammals, the clearest cases occurring among wolves, wild dogs, dolphins, monkeys, and apes.

In short, kin altruism and reciprocity do exist, at least in some nonhuman animals living in groups. Could these forms of behaviour be the basis of human ethics? There are good reasons for believing that they could. A surprising proportion of human morality can be derived from the twin bases of concern for kin and reciprocity. Kinship is a source of obligation in every human society. A mother's duty to look after her children seems so obvious that it scarcely needs to be mentioned. The duty of a married man to support and protect his family is almost equally as widespread. Duties to close relatives take priority over duties to more distant relatives, but in most societies even distant relatives are still treated better than strangers.

Concern for kin and reciprocity

If kinship is the most basic and universal tie between human beings, the bond of reciprocity is not far behind. It would be difficult to find a society that did not recognize, at least under some circumstances, an obligation to return favours. In many cultures this is taken to extraordinary lengths, and there are elaborate rituals of gift giving. Often the repayment has to be superior to the original gift, and this escalation can reach such extremes as to threaten the economic security of the donor. The huge "potlatch" feasts of certain American Indian tribes are a well-known example of this type of situation. Many Melanesian soci-

eties also place great importance on giving and receiving very substantial amounts of valuable items.

Many features of human morality could have grown out of simple reciprocal practices such as the mutual removal of parasites from awkward places. Suppose I want to have the lice in my hair picked out and I am willing in return to remove lice from someone else's hair. I must, however, choose my partner carefully. If I help everyone indiscriminately, I will find myself delousing others without getting my own lice removed. To avoid this, I must learn to distinguish between those who return favours and those who do not. In making this distinction, I am separating reciprocators and nonreciprocators and, in the process, developing crude notions of fairness and of cheating. I will strengthen my links with those who reciprocate, and bonds of friendship and loyalty, with a consequent sense of obligation to assist, will result.

This is not all. The reciprocators are likely to react in a hostile and angry way to those who do not reciprocate. Perhaps they will regard reciprocity as good and "right" and cheating as bad and "wrong." From here it is a small step to concluding that the worst of the nonreciprocators should be driven out of society or else punished in some way, so that they will not take advantage of others again. Thus a system of punishment and a notion of desert constitute the other side of reciprocal altruism.

Although kinship and reciprocity loom large in human morality, they do not cover the entire field. Typically, there are obligations to other members of the village, tribe, or nation even when these are strangers. There may also be a loyalty to the group as a whole that is distinct from loyalty to individual members of the group. It may be at this point that human culture intervenes. Each society has a clear interest in promoting devotion to the group and can be expected to develop cultural influences that exalt those who make sacrifices for the sake of the group and revile those who put their own interests too far ahead of the interests of the group. More tangible rewards and punishments may supplement the persuasive effect of social opinion. This is simply the start of a process of cultural development of moral codes.

Before considering the cultural variations in human morality and their significance for ethics, let us draw together this discussion of the origins of morality. Since we are dealing with a prehistoric period and morality leaves no fossils, any account of the origins of morality will necessarily remain to some extent speculative. It seems likely that morality is the gradual outgrowth of forms of altruism that exist in some social animals and that are the result of the usual evolutionary processes of natural selection. No myths are required to explain its existence.

ANTHROPOLOGY AND ETHICS

It is commonly believed that there are no ethical universals—*i.e.*, there is so much variation from one culture to another that no single principle or judgment is generally accepted. We have already seen that such is not the case. Of course, there are immense differences in the way in which the broad principles so far discussed are applied. The duty of children to their parents meant one thing in traditional Chinese society and means something quite different in contemporary Anglo-Saxon society. Yet, concern for kin and reciprocity to those who treat us well are considered good in virtually all human societies. Also, all societies have, for obvious reasons, some constraints on killing and wounding other members of the group.

Beyond that common ground, the variations in moral attitudes soon become more striking than the similarities. Man's fascination with such variations goes back a long way. The Greek historian Herodotus relates that Darius, king of Persia, once summoned Greeks before him and asked them how much he would have to pay them to eat their fathers' dead bodies. They refused to do it at any price. Then Darius brought in some Indians who by custom ate the bodies of their parents and asked them what would make them willing to burn their fathers' bodies. The Indians cried out that he should not mention so horrid an act. Herodotus drew the obvious moral: each nation thinks its own customs best.

Variations in morals were not systematically studied until the 19th century, when knowledge of the more remote parts of the globe began to increase. At the beginning of the 20th century, Edward Westermarck published *The Origin and Development of the Moral Ideas* (1906–08), two large volumes comparing differences among societies in such matters as the wrongness of killing (including killing in warfare, euthanasia, suicide, infanticide, abortion, human sacrifices, and duelling); whose duty it is to support children, the aged, or the poor; the forms of sexual relationship permitted; the status of women; the right to property and what constitutes theft; the holding of slaves; the duty to tell the truth; dietary restrictions; concern for nonhuman animals; duties to the dead; and duties to the gods. Westermarck had no difficulty in demonstrating tremendous diversity in all these issues. More recent, though less comprehensive, studies have confirmed that human societies can and do flourish while holding radically different views about all such matters.

As noted earlier, ethics itself is not primarily concerned with the description of moral systems in different societies. That task, which remains on the level of description, is one for anthropology or sociology. In contrast, ethics deals with the justification of moral principles. Nevertheless, ethics must take note of the variations in moral systems because it has often been claimed that this knowledge shows that morality is simply a matter of what is customary and is always relative to a particular society. According to this view, no ethical principles can be valid except in terms of the society in which they are held. Words such as good and bad just mean, it is claimed, "approved in my society" or "disapproved in my society," and so to search for an objective, or rationally justifiable, ethic is to search for what is in fact an illusion.

One way of replying to this position would be to stress the fact that there are some features common to virtually all human moralities. It might be thought that these common features must be the universally valid and objective core of morality. This argument would, however, involve a fallacy. If the explanation for the common features is simply that they are advantageous in terms of evolutionary theory, that does not make them right. Evolution is a blind force incapable of conferring a moral imprimatur on human behaviour. It may be a fact that concern for kin is in accord with evolutionary theory, but to say that concern for kin is therefore right would be to attempt to deduce values from facts. As will be seen later, it is not possible to deduce values from facts in this manner. In any case, that something is universally approved does not make it right. If all human societies enslaved any tribe they could conquer, some freethinking moralists might still insist that slavery is wrong. They could not be said to be talking nonsense merely because they had few supporters. Similarly, then, universal support for principles of kinship and reciprocity cannot prove that these principles are in some way objectively justified.

This example illustrates the way in which ethics differs from a descriptive science. From the standpoint of ethics, whether human moral codes closely parallel one another or are extraordinarily diverse, the question of how an individual should act remains open. If you are thinking deeply about what you should do, your uncertainty will not be overcome by being told what your society thinks you should do in the circumstances in which you find yourself. Even if you are told that virtually all other human societies agree, you may choose not to go that way. If you are told that there is great variation among human societies over what people should do in your circumstances, you may wonder whether there can be any objective answer, but your dilemma has still not been resolved. In fact, this diversity does not rule out the possibility of an objective answer either: conceivably, most societies simply got it wrong. This, too, is something that will be taken up later in this article, for the possibility of an objective morality is one of the constant themes of ethics.

ANCIENT ETHICS

The first ethical precepts were certainly passed down by word of mouth by parents and elders, but as societies

learned to use the written word, they began to set down their ethical beliefs. These records constitute the first historical evidence of the origins of ethics.

The Middle East. The earliest surviving writings that might be taken as ethics textbooks are a series of lists of precepts to be learned by boys of the ruling class of Egypt, prepared some 3,000 years before the Christian Era. In most cases, they consist of shrewd advice on how to live happily, avoid unnecessary troubles, and advance one's career by cultivating the favour of superiors. There are, however, several passages that recommend more broadly based ideals of conduct, such as the following: Rulers should treat their people justly and judge impartially between their subjects. They should aim to make their people prosperous. Those who have bread are urged to share it with the hungry. Humble and lowly people must be treated with kindness. One should not laugh at the blind or at dwarfs.

Why then should one follow these precepts? Did the ancient Egyptians believe that one should do what is good for its own sake? The precepts frequently state that it will profit a man to act justly, much as we say that "honesty is the best policy." They also emphasize the importance of having a good name. Since these precepts are intended for the instruction of the ruling classes, however, we have to ask why helping the destitute should have contributed to an individual's good reputation among this class. To some degree the authors of the precepts must have thought that to make people prosperous and happy and to be kind to those who have least is not merely personally advantageous but good in itself.

The precepts are not works of ethics in the philosophical sense. No attempt is made to find any underlying principles of conduct that might provide a more systematic understanding of ethics. Justice, for example, is given a prominent place, but there is no elaboration of the notion of justice nor any discussion of how disagreements about what is just and unjust might be resolved. Furthermore, there is no probing of ethical dilemmas that may occur if the precepts should conflict with one another. The precepts are full of sound observations and practical wisdom, but they do not encourage theoretical speculation.

The same practical bent can be found in other early codes or lists of ethical injunctions. The great codification of Babylonian law by Hammurabi is often said to have been based on the principle of "an eye for an eye, a tooth for a tooth," as if this were some fundamental principle of justice, elaborated and applied to all cases. In fact, the code reflects no such consistent principle. It frequently prescribes the death penalty for offenses that do not themselves cause death—*e.g.*, for robbery or for accepting bribes. Moreover, even the eye-for-an-eye rule applies only if the eye of the original victim is that of a member of the patrician class; if it is the eye of a commoner, the punishment is a fine of a quantity of silver. Apparently such differences in punishment were not thought to require justification. At any rate, there are no surviving attempts to defend the principles of justice on which the code was based.

Code of Hammurabi

The Hebrew people were at different times captives of both the Egyptians and the Babylonians. It is therefore not surprising that the law of ancient Israel, which was put into its definitive form during the Babylonian Exile, shows the influence both of the ancient Egyptian precepts and of the Code of Hammurabi. The book of Exodus refers, for example, to the principle of "life for life, eye for eye, tooth for tooth." Hebrew law does not differentiate, as the Babylonian law does, between patricians and commoners, but it does stipulate that in several respects foreigners may be treated in ways that it is not permissible to treat fellow Hebrews; for instance, Hebrew slaves, but not others, had to be freed without ransom in the seventh year. Yet, in other respects Israeli law and morality developed the humane concern shown in the Egyptian precepts for the poor and unfortunate: hired servants must be paid promptly, because they rely on their wages to satisfy their pressing needs; slaves must be allowed to rest on the seventh day; widows, orphans, and the blind and deaf must not be wronged, and the poor man should not be refused a loan. There was even a tithe providing for an incipient welfare state. The spirit of this humane concern was summed up by the injunction to "love thy neighbour as thyself," a sweepingly generous form of the rule of reciprocity.

The famed Ten Commandments are thought to be a legacy of Semitic tribal law when important commands were taught, one for each finger, so that they could more easily be remembered. (Sets of five or 10 laws are common among preliterate civilizations.) The content of the Hebrew commandments differed from other laws of the region mainly in its emphasis on duties to God. In the more detailed laws laid down elsewhere, this emphasis continued with as much as half the legislation concerned with crimes against God and ceremonial and ritualistic matters, though there may be other explanations for some of these ostensibly religious requirements concerning the avoidance of certain foods and the need for ceremonial cleansings.

In addition to lengthy statements of the law, the surviving literature of ancient Israel includes both proverbs and the books of the prophets. The proverbs, like the precepts of the Egyptians, are brief statements without much concern for systematic presentation or overall coherence. They go further than the Egyptian precepts, however, in urging conduct that is just and upright and pleasing to God. There are correspondingly fewer references to what is needed for a successful career, although it is frequently stated that God rewards the just. In this connection the Book of Job is notable as an exploration of the problem raised for those who accept this motive for obeying the moral law: How are we to explain the fact that the best of people may suffer the worst misfortunes? The book offers no solution beyond faith in God, but the sharpened awareness of the problem it offers may have influenced some to adopt belief in reward and punishment in another realm as the only possible solution.

Hebrew proverbs and the books of the prophets

The literature of the prophets contains a good deal of social and ethical criticism, though more at the level of denunciation than discussion about what goodness really is or why there is so much wrongdoing. The Book of Isaiah is especially notable for its early portrayal of a utopia in which "the desert shall blossom as the rose . . . the wolf also shall dwell with the lamb . . . . They shall not hurt or destroy in all my holy mountain."

India. Unlike the ethical teaching of ancient Egypt and Babylon, Indian ethics was philosophical from the start. In the oldest of the Indian writings, the Vedas, ethics is an integral aspect of philosophical and religious speculation about the nature of reality. These writings date from about 1500 BC. They have been described as the oldest philosophical literature in the world, and what they say about how people ought to live may therefore be the first philosophical ethics.

The Vedas

The Vedas are, in a sense, hymns, but the gods to which they refer are not persons but manifestations of ultimate truth and reality. In the Vedic philosophy, the basic principle of the universe, the ultimate reality on which the cosmos exists, is the principle of *Ritam,* which is the word from which the Western notion of right is derived. There is thus a belief in a right moral order somehow built into the universe itself. Hence, truth and right are linked; to penetrate through illusion and understand the ultimate truth of human existence is to understand what is right. To be an enlightened one is to know what is real and to live rightly, for these are not two separate things but one and the same.

The ethic that is thus traced to the very essence of the universe is not without its detailed practical applications. These were based on four ideals, or proper goals, of life: prosperity, the satisfaction of desires, moral duty, and spiritual perfection—*i.e.*, liberation from a finite existence. From these ends follow certain virtues: honesty, rectitude, charity, nonviolence, modesty, and purity of heart. To be condemned, on the other hand, are falsehood, egoism, cruelty, adultery, theft, and injury to living things. Because the eternal moral law is part of the universe, to do what is praiseworthy is to act in harmony with the universe and accordingly will receive its proper reward; conversely, once the true nature of the self is understood, it becomes

apparent that those who do what is wrong are acting self-destructively.

The basic principles underwent considerable modification over the ensuing centuries, especially in the *Upaniṣads*, a body of philosophical literature dating from 800 BC. The Indian caste system, with its intricate laws about what members of each caste may or may not do, is accepted by the *Upaniṣads* as part of the proper order of the universe. Ethics itself, however, is not regarded as a matter of conformity to laws. Instead, the desire to be ethical is an inner desire. It is part of the quest for spiritual perfection, which in turn is elevated to the highest of the four goals of life.

During the following centuries the ethical philosophy of this early period gradually became a rigid and dogmatic system that provoked several reactions. One, which is uncharacteristic of Indian thought in general, was the Cārvāka, or materialist school, which mocked religious ceremonies, saying that they were invented by the Brahmans (the priestly caste) to ensure their livelihood. When the Brahmans defended animal sacrifices by claiming that the sacrificed beast goes straight to heaven, the members of the Cārvāka asked why the Brahmans did not kill their aged parents to hasten their arrival in heaven. Against the postulation of an eventual spiritual liberation, Cārvāka ethics urged each individual to seek his or her pleasure here and now.

The Cārvāka

Jainism, another reaction to the traditional Vedic outlook, went in exactly the opposite direction. The Jaina philosophy is based on spiritual liberation as the highest of all goals and nonviolence as the means to it. In true philosophical manner, the Jainas found in the principle of nonviolence a guide to all morality. First, apart from the obvious application to prohibiting violent acts to other humans, nonviolence is extended to all living things. The Jainas are vegetarian. They are often ridiculed by Westerners for the care they take to avoid injuring insects or other living things while walking or drinking water that may contain minute organisms; it is less well known that Jainas began to care for sick and injured animals thousands of years before animal shelters were thought of in Europe. The Jainas do not draw the distinction usually made in Western ethics between their responsibility for what they do and their responsibility for what they omit doing. Omitting to care for an injured animal would also be in their view a form of violence.

Jaina philosophy

Other moral duties are also derived from the notion of nonviolence. To tell someone a lie, for example, is regarded as inflicting a mental injury on that person. Stealing, of course, is another form of injury, but because of the absence of a distinction between acts and omissions, even the possession of wealth is seen as depriving the poor and hungry of the means to satisfy their wants. Thus nonviolence leads to a principle of nonpossession of property. Jaina priests were expected to be strict ascetics and to avoid sexual intercourse. Ordinary Jainas, however, followed a slightly less severe code, which was intended to give effect to the major forms of nonviolence while still being compatible with a normal life.

The other great ethical system to develop as a reaction to the ossified form of the old Vedic philosophy was Buddhism. The person who became known as the Buddha, which means the "enlightened one," was born about 563 BC, the son of a king. Until he was 29 years old, he lived the sheltered life of a typical prince, with every luxury he could desire. At that time, legend has it, he was jolted out of his idleness by the "Four Signs": he saw in rapid succession a very feeble old man, a hideous leper, a funeral, and a venerable ascetic monk. He began to think about old age, disease, and death, and decided to follow the way of the monk. For six years he led an ascetic life of renunciation, but finally, while meditating under a tree, he concluded that the solution was not withdrawal from the world, but rather a practical life of compassion for all.

Buddhism is often thought to be a religion, and indeed over the centuries it has adopted in many places the trappings of religion. This is an irony of history, however, because the Buddha himself was a strong critic of religion. He rejected the authority of the Vedas and refused to set up any alternative creed. He saw religious ceremonies as a waste of time and theological beliefs as mere superstition. He refused to discuss abstract metaphysical problems such as the immortality of the soul. The Buddha told his followers to think for themselves and take responsibility for their own future. In place of religious beliefs and religious ceremonies, the Buddha advocated a life devoted to universal compassion and brotherhood. Through such a life one might reach the ultimate goal, Nirvāṇa, a state in which all living things are free from pain and sorrow. There are similarities between this ethic of universal compassion and the ethics of the Jainas. Nevertheless, the Buddha was the first historical figure to develop such a boundless ethic.

The teachings of the Buddha

In keeping with his own previous experience, the Buddha proposed a "middle path" between self-indulgence and self-renunciation. In fact, it is not so much a path between these two extremes as one that draws together the benefits of both. Through living a life of compassion and love for all, a person achieves the liberation from selfish cravings sought by the ascetic and a serenity and satisfaction that are more fulfilling than anything obtained by indulgence in pleasure.

It is sometimes thought that because the Buddhist goal is Nirvāṇa, a state of freedom from pain and sorrow that can be reached by meditation, Buddhism teaches a withdrawal from the real world. Nirvāṇa, however, is not to be sought for oneself alone; it is regarded as a unity of the individual self with the universal self in which all things take part. In the Mahāyāna school of Buddhism, the aspirant for Enlightenment even takes a vow not to accept final release until everything that exists in the universe has attained Nirvāṇa.

The Buddha lived and taught in India, and so Buddhism is properly classified as an Indian ethical philosophy. Yet, Buddhism did not take hold in the land of its origin. Instead, it spread in different forms south into Sri Lanka and Southeast Asia, and north through Tibet to China, Korea, and Japan. In the process, Buddhism suffered the same fate as the Vedic philosophy against which it had rebelled: it became a religion, often rigid, with its own sects, ceremonies, and superstitions.

China. The two greatest moral philosophers of ancient China, Lao-tzu (flourished *c.* 6th century BC) and Confucius (551–479 BC), thought in very different ways. Lao-tzu is best known for his ideas about the Tao (literally "Way," the Supreme Principle). The Tao is based on the traditional Chinese virtues of simplicity and sincerity. To follow the Tao is not a matter of keeping to any set list of duties or prohibitions, but rather of living in a simple and honest manner, being true to oneself, and avoiding the distractions of ordinary living. Lao-tzu's classic book on the Tao, *Tao-te Ching*, consists only of aphorisms and isolated paragraphs, making it difficult to draw an intelligible system of ethics from it. Perhaps this is because Lao-tzu was a type of moral skeptic: he rejected both righteousness and benevolence, apparently because he saw them as imposed on individuals from without rather than coming from their own inner nature. Like the Buddha, Lao-tzu found the things prized by the world—rank, luxury, and glamour—to be empty, worthless values when compared with the ultimate value of the peaceful inner life. He also emphasized gentleness, calm, and nonviolence. Nearly 600 years before Jesus, he said: "It is the way of the Tao . . . to recompense injury with kindness." By returning good for good and also good for evil, Lao-tzu believed that all would become good; to return evil for evil would lead to chaos.

Lao-tzu

The lives of Lao-tzu and Confucius overlapped, and there is even an account of a meeting between them, which is said to have left the younger Confucius baffled. Confucius was the more down-to-earth thinker, absorbed in the practical task of social reform. When he was a provincial minister of justice, the province became renowned for the honesty of its people and their respect for the aged and their care for the poor. Probably because of its practical nature, the teachings of Confucius had a far greater influence on China than did those of the more withdrawn Lao-tzu.

Confucius did not organize his recommendations into

The teachings of Confucius

any coherent system. His teachings are offered in the form of sayings, aphorisms, and anecdotes, usually in reply to questions by disciples. They aim at guiding the audience in what is necessary to become a better person, a concept translated as "gentleman" or "the superior man." In opposition to the prevailing feudal ideal of the aristocratic lord, Confucius presented the superior man as one who is humane and thoughtful, motivated by the desire to do what is good rather than by personal profit. Beyond this, however, the concept is not discussed in any detail; it is only shown by diverse examples, some of them trite: "A superior man's life leads upwards .... The superior man is broad and fair; the inferior man takes sides and is petty .... A superior man shapes the good in man; he does not shape the bad in him."

One of the recorded sayings of Confucius is an answer to a request from a disciple for a single word that could serve as a guide to conduct for one's entire life. He replied: "Is not reciprocity such a word? What you do not want done to yourself, do not do to others." This rule is repeated several times in the Confucian literature and might be considered the supreme principle of Confucian ethics. Other duties are not, however, presented as derivative from this supreme principle, nor is the principle used to determine what is to be done when more specific duties—*e.g.*, duties to parents and duties to friends, both of which were given prominence in Confucian ethics—should clash.

Confucius did not explain why the superior man chose righteousness rather than personal profit. This question was taken up more than 100 years after his death by his follower Mencius, who asserted that humans are naturally inclined to do what is humane and right. Evil is not in human nature but is the result of poor upbringing or lack of education. But Confucius also had another distinguished follower, Hsün-tzu, who said that man's nature is to seek self-profit and to envy others. The rules of morality are designed to avoid the strife that would otherwise follow from this nature. The Confucian school was united in its ideal of the superior man but divided over whether such an ideal was to be obtained by allowing people to fulfill their natural desires or by educating them to control those desires.

Ancient Greece. Early Greece was the birthplace of Western philosophical ethics. The ideas of Socrates, Plato, and Aristotle, who flourished in the 5th and 4th centuries BC, will be discussed in the next section. The sudden blooming of philosophy during that period had its roots in the ethical thought of earlier centuries. In the poetic literature of the 7th and 6th centuries BC, there were, as in the early development of ethics in other cultures, ethical precepts but no real attempts to formulate a coherent overall ethical position. The Greeks were later to refer to the most prominent of these poets and early philosophers as the seven sages, and they are frequently quoted with respect by Plato and Aristotle. Knowledge of the thought of this period is limited, for often only fragments of original writings, along with later accounts of dubious accuracy, remain.

Pythagoras (*c.* 580–*c.* 500 BC), whose name is familiar because of the geometrical theorem that bears his name, is one such early Greek thinker about whom little is known. He appears to have written nothing at all, but he was the founder of a school of thought that touched on all aspects of life and that may have been a kind of philosophical and religious order. In ancient times the school was best known for its advocacy of vegetarianism, which, like that of the Jainas, was associated with the belief that after the death of the body, the human soul may take up residence in the body of an animal. Pythagoreans continued to espouse this view for many centuries, and classical passages in the works of such writers as Ovid and Porphyry opposing bloodshed and animal slaughter can be traced back to Pythagoras.

Pythagorean school of thought

Ironically, an important stimulus for the development of moral philosophy came from a group of teachers to whom the later Greek philosophers—Socrates, Plato, and Aristotle—were consistently hostile: the Sophists. This term was used in the 5th century to refer to a class of professional teachers of rhetoric and argument. The Sophists promised their pupils success in political debate and increased influence in the affairs of the city. They were accused of being mercenaries who taught their students to win arguments by fair means or foul. Aristotle said that Protagoras, perhaps the most famous of them, claimed to teach how "to make the weaker argument the stronger."

The Sophists

The Sophists, however, were more than mere teachers of rhetorical tricks. They saw their role as imparting the cultural and intellectual qualities necessary for success, and their involvement with argument about practical affairs led them to develop views about ethics. The recurrent theme in the views of the better known Sophists, such as Protagoras, Antiphon, and Thrasymachus, is that what is commonly called good and bad or just and unjust does not reflect any objective fact of nature but is rather a matter of social convention. It is to Protagoras that we owe the celebrated epigram summing up this theme, "Man is the measure of all things." Plato represents him as saying "Whatever things seem just and fine to each city, are just and fine for that city, so long as it thinks them so." Protagoras, like Herodotus, was an early social relativist, but he drew a moderate conclusion from his relativism. He argued that while the particular content of the moral rules may vary, there must be rules of some kind if life is to be tolerable. Thus Protagoras stated that the foundations of an ethical system needed nothing from the gods or from any special metaphysical realm beyond the ordinary world of the senses.

The Sophist Thrasymachus appears to have taken a more radical approach—if Plato's portrayal of his views is historically accurate. He explained that the concept of justice means nothing more than obedience to the laws of society, and, since these laws are made by the strongest political group in their own interests, justice represents nothing but the interests of the stronger. This position is often represented by the slogan "Might is right." Thrasymachus was probably not saying, however, that whatever the mightiest do really is right; he is more likely to have been denying that the distinction between right and wrong has any objective basis. Presumably he would then encourage his pupils to follow their own interests as best they could. He is thus an early representative of Skepticism about morals and perhaps of a form of egoism, the view that the rational thing to do is follow one's own interests.

It is not surprising that with ideas of this sort in circulation other thinkers should react by probing more deeply into ethics to see if the potentially destructive conclusions of some of the Sophists could be resisted. This reaction produced works that have served ever since as the cornerstone for the entire edifice of Western ethics.

Western ethics from Socrates to the 20th century

THE CLASSICAL PERIOD OF GREEK ETHICS

Socrates. "The unexamined life is not worth living," Socrates once observed. This thought typifies his questioning, philosophical approach to ethics. Socrates, who lived from about 470 BC until he was put to death in 399 BC, must be regarded as one of the greatest teachers of ethics. Yet, unlike other figures of comparable importance such as the Buddha or Confucius, he did not tell his audience how they should live. What Socrates taught was a method of inquiry. When the Sophists or their pupils boasted that they knew what justice, piety, temperance, or law was, Socrates would ask them to give an account of it and then show that the account offered was entirely inadequate. For instance, against the received wisdom that justice consists in keeping promises and paying debts, Socrates put forth the example of a person faced with an unusual situation: a friend from whom he borrowed a weapon has since become insane but wants the weapon back. Conventional morality gives no clear answer to this dilemma; therefore, the original definition of justice has to be reformulated. So the Socratic dialogue gets under way.

Because his method of inquiry threatened conventional beliefs, Socrates' enemies contrived to have him put to death on a charge of corrupting the youth of Athens. For those who saw adherence to the conventional moral

code as more desirable than the cultivation of an inquiring mind, the charge was appropriate. By conventional standards, Socrates was indeed corrupting the youth of Athens, but he himself saw the destruction of beliefs that could not stand up to criticism as a necessary preliminary to the search for true knowledge. Here, he differed from the Sophists with their moral relativism, for he thought that virtue is something that can be known and that the good person is the one who knows of what virtue, or justice, consists.

It is therefore not entirely accurate to see Socrates as contributing a method of inquiry but no positive views of his own. He believed in goodness as something that can be known, even though he did not himself profess to know it. He also thought that those who know what good is are in fact good. This latter belief seems peculiar today, because we make a sharp distinction between what is good and what is in a person's own interests. Accordingly, it does not seem surprising if people know what they ought morally to do but then proceed to do what is in their own interests instead. How to provide such people with reasons for doing what is right has been a major problem for Western ethics. Socrates did not see a problem here at all; in his view anyone who does not act well must simply be ignorant of the nature of goodness. Socrates could say this because in ancient Greece the distinction between goodness and self-interest was not made, or at least not in the clear-cut manner that it is today. The Greeks believed that virtue is good both for the individual and for the community. To be sure, they recognized that to live virtuously might not be the best way to prosper financially, but then they did not assume, as we are prone to do, that material wealth is a major factor in whether a person's life goes well or ill.

Plato. Socrates' greatest disciple, Plato (428/427–348/347 BC), accepted the key Socratic beliefs in the objectivity of goodness and in the link between knowing what is good and doing it. He also took over the Socratic method of conducting philosophy, developing the case for his own positions by exposing errors and confusions in the arguments of his opponents. He did this by writing his works as dialogues in which Socrates is portrayed as engaging in argument with others, usually Sophists. The early dialogues are generally accepted as reasonably accurate accounts of Socrates' views, but the later ones, written many years after the death of Socrates, use the latter as a mouthpiece for ideas and arguments that were Plato's rather than those of the historical Socrates.

In the most famous of Plato's dialogues, *Politeia* (*The Republic*), the imaginary Socrates is challenged by the following example: Suppose a person obtained the legendary ring of Gyges, which has the magical property of rendering the wearer invisible. Would that person still have any reason to behave justly? Behind this challenge lies the suggestion, made by the Sophists and still heard today, that the only reason for acting justly is that one cannot get away with acting unjustly. Plato's response to this challenge is a long argument developing a position that appears to go beyond anything the historical Socrates asserted. Plato maintained that true knowledge consists not in knowing particular things but in knowing something general that is common to all the particular cases. This is obviously derived from the way in which Socrates would press his opponents to go beyond merely describing particular good, or temperate, or just acts, and to give instead a general account of goodness, or temperance, or justice. The implication is that we do not know what goodness is unless we can give this general account. But the question then arises, what is it that we know when we know this general idea of gōodness? Plato's answer seems to be that what we know is some general form or idea of goodness, which is shared by every particular thing that is good. Yet, if we are truly to be able to know this form or idea of goodness, it seems to follow that it must really exist. Plato accepts this implication. His theory of forms is the view that when we know what goodness is, we have knowledge of something that is the common element in virtue of which all good things are good and, at the same time, is some existing thing, the pure form of goodness.

It has been said that all of Western philosophy consists of footnotes to Plato. Certainly the central issue around which all of Western ethics has revolved can be traced back to the debate between the Sophists, on the one hand, with their claims that goodness and justice are relative to the customs of each society or, worse still, merely a disguise for the interests of the stronger, and, on the other, Plato's defense of the possibility of knowledge of an objective form or idea of goodness.

But even if we know what goodness or justice is, why should we act justly if we can profit by doing the opposite? This remaining part of the challenge posed by the legendary ring of Gyges is still to be answered, for even if we accept that goodness is objective, it does not follow that we all have sufficient reason to do what is good. Whether goodness leads to happiness is, as has been seen from the preceding discussion of early ethics in other cultures, a perennial topic for all who think about ethics. Plato's answer is that justice consists in harmony between the three elements of the soul: intellect, emotion, and desire. The unjust person lives in an unsatisfactory state of internal discord, trying always to overcome the discomfort of unsatisfied desire but never achieving anything better than the mere absence of want. The soul of the good person, on the other hand, is harmoniously ordered under the governance of reason, and the good person finds truly satisfying enjoyment in the pursuit of knowledge. Plato remarks that the highest pleasure, in fact, comes from intellectual speculation. He also gives an argument for the belief that the human soul is immortal; therefore, even if just individuals seem to be living in poverty or illness, the gods will not neglect them in the next life, and there they will have the greatest rewards of all. In summary, then, Plato asserts that we should act justly because in doing so we are "at one with ourselves and with the gods."

Plato's concept of justice

Today, this may seem like a strange account of justice and a farfetched view of what it takes to achieve human happiness. Plato does not recommend justice for its own sake, independently of any personal gains one might obtain from being a just person. This is characteristic of Greek ethics, with its refusal to recognize that there could be an irresolvable conflict between one's own interest and the good of the community. Not until Immanuel Kant, in the 18th century, does a philosopher forcefully assert the importance of doing what is right simply because it is right quite apart from self-interested motivation. To be sure, Plato must not be interpreted as holding that the motivation for each and every just act is some personal gain; on the contrary, the person who takes up justice will do what is just because it is just. Nevertheless, Plato accepts the assumption of his opponents that one could not recommend taking up justice in the first place unless doing so could be shown to be advantageous for oneself as well as for others.

In spite of the fact that many people now think differently about this connection between morality and self-interest, Plato's attempt to argue that those who are just are in the long run happier than those who are unjust has had an enormous influence on Western ethics. Like Plato's views on the objectivity of goodness, the claim that justice and personal happiness are linked has helped to frame the agenda for a debate that continues even today.

Aristotle. Plato founded a school of philosophy in Athens known as the Academy. Here Aristotle (384–322 BC), Plato's younger contemporary and only rival in terms of influence on the course of Western philosophy, came to study. Aristotle was often fiercely critical of Plato, and his writing is very different in style and content, but the time they spent together is reflected in a considerable amount of common ground. Thus Aristotle holds with Plato that the life of virtue is rewarding for the virtuous, as well as beneficial for the community. Aristotle also agrees that the highest and most satisfying form of human existence is that in which man exercises his rational faculties to the fullest extent. One major difference is that Aristotle does not accept Plato's theory of common essences, or universal ideas, existing independently of particular things. Thus he does not argue that the path to goodness is through knowledge of the universal form or idea of "the good."

The basis of Aristotle's ethics

Aristotle's ethics are based on his view of the universe. He saw it as a hierarchy in which everything has a function. The highest form of existence is the life of the rational being, and the function of lower beings is to serve this form of life. This led him to defend slavery—because he thought barbarians were less rational than Greeks and by nature suited to be "living tools"—and the killing of non-human animals for food or clothing. From this also came a view of human nature and an ethical theory derived from it. All living things, Aristotle held, have inherent potentialities and it is their nature to develop that potential to the full. This is the form of life properly suited to them and constitutes their goal. What, however, is the potentiality of human beings? For Aristotle this question turns out to be equivalent to asking what it is that is distinctive about human beings, and this, of course, is the capacity to reason. The ultimate goal of humans, therefore, is to develop their reasoning powers. When they do this, they are living well, in accordance with their true nature, and they will find this the most rewarding existence possible.

Aristotle thus ends up agreeing with Plato that the life of the intellect is the highest form of life; though having a greater sense of realism than Plato, he tempered this view with the suggestion that the best feasible life for humans must also have the goods of material prosperity and close friendships. Aristotle's argument for regarding the life of the intellect so highly, however, is different from that used by Plato; and the difference is significant because Aristotle committed a fallacy that has often been repeated. The fallacy is to assume that whatever capacity distinguishes humans from other beings is, for that very reason, the highest and best of their capacities. Perhaps the ability to reason is the best of our capacities, but we cannot be compelled to draw this conclusion from the fact that it is what is most distinctive of the human species.

A broader and still more pervasive fallacy underlies Aristotle's ethics. It is the idea that an investigation of human nature can reveal what we ought to do. For Aristotle, an examination of a knife would reveal that its distinctive quality is to cut, and from this we could conclude that a good knife would be a knife that cuts well. In the same way, an examination of human nature should reveal the distinctive quality of human beings, and from this we should be able to conclude what it is to be a good human being. This line of thought makes sense if we think, as Aristotle did, that the universe as a whole has a purpose and that we exist as part of such a goal-directed scheme of things, but its error becomes glaring once we reject this view and come to see our existence as the result of a blind process of evolution. Then we know that the standards of quality for knives are a result of the fact that knives are made with a specific purpose in mind and that a good knife is one that fills this purpose well. Human beings, however, were not made with any particular purpose in mind. Their nature is the result of random forces of natural selection and thus cannot, without further moral premises, determine how they ought to live.

Concept of the final end

It is to Aristotle that we owe the notion of the final end, or, as it was later called by medieval scholars, the *summum bonum*—the overall good for human beings. This can be found, Aristotle wrote, by asking why we do the things that we do. If we ask why we chop wood, the answer may be to build a fire; and if we ask why we build a fire, it may be to keep warm; but, if we ask why we keep warm, the answer is likely to be simply that it is pleasant to be warm and unpleasant to be cold. We can ask the same kind of questions about other activities; the answer always points, Aristotle thought, to what he called *eudaimonia*. This Greek word is usually translated as "happiness," but this is only accurate if we understand that term in its broadest sense to mean living a fulfilling, satisfying life. Happiness in the narrower sense of joy or pleasure would certainly be a concomitant of such a life, but it is not happiness in this narrower sense that is the goal.

In searching for the overall good, Aristotle separates what may be called instrumental goods from intrinsic goods. The former are good only because they lead to something else that is good; the latter are good in themselves. The distinction is neglected in the early lists of ethical precepts that were surveyed above, but it is of the first importance if a firmly grounded answer to questions about how one ought to live is to be obtained.

Aristotle is also responsible for much later thinking about the virtues one should cultivate. In his most important ethical treatise, the *Ethica Nicomachea* (*Nicomachean Ethics*), he sorts through the virtues as they were popularly understood in his day, specifying in each case what is truly virtuous and what is mistakenly thought to be so. Here, he uses the idea of the Golden Mean, which is essentially the same idea as the Buddha's middle path between self-indulgence and self-renunciation. Thus courage, for example, is the mean between two extremes: one can have a deficiency of it, which is cowardice, or one can have an excess of it, which is foolhardiness. The virtue of friendliness, to give another example, is the mean between obsequiousness and surliness.

Aristotle does not intend the idea of the mean to be applied mechanically in every instance: he says that in the case of the virtue of temperance, or self-restraint, it is easy to find the excess of self-indulgence in the physical pleasures, but the opposite error, insufficient concern for such pleasures, scarcely exists. (The Buddha, with his experience of the ascetic life of renunciation, would not have agreed.) This caution in the application of the idea is just as well, for while it may be a useful device for moral education, the notion of a mean cannot help us to discover new truths about virtue. We can only arrive at the mean if we already have a notion as to what is an excess and what is a defect of the trait in question, but this is not something to be discovered by a morally neutral inspection of the trait itself. We need a prior conception of the virtue in order to decide what is excessive and what is defective. To attempt to use the doctrine of the mean to define the particular virtues would be to travel in a circle.

Aristotle's list of the virtues differs from later Christian lists. Courage, temperance, and liberality are common to both periods, but Aristotle also includes a virtue that literally means "greatness of soul." This is the characteristic of holding a high opinion of oneself. The corresponding vice of excess is unjustified vanity, but the vice of deficiency is humility, which for Christians is a virtue.

Aristotle's discussion of the virtue of justice has been the starting point for almost all Western accounts. He distinguishes between justice in the distribution of wealth or other goods and justice in reparation, as, for example, in punishing someone for a wrong he has done. The key element of justice, according to Aristotle, is treating like cases alike—an idea that has set later thinkers the task of working out which similarities (need, desert, talent) are relevant. As with the notion of virtue as a mean, Aristotle's conception of justice provides a framework that needs to be filled in before it can be put to use.

Theoretical and practical reason

Aristotle distinguished between theoretical and practical wisdom. His concept of practical wisdom is significant, for it goes beyond merely choosing the means best suited to whatever ends or goals one may have. The practically wise person also has the right ends. This implies that one's ends are not purely a matter of brute desires or feelings; the right ends are something that can be known. It also gives rise to the problem that faced Socrates: How is it that people can know the difference between good and bad and still choose what is bad? As noted earlier, Socrates simply denied that this could happen, saying that those who did not choose the good must, appearances notwithstanding, be ignorant of what it is. Aristotle said that this view of Socrates was "plainly at variance with the observed facts" and, instead, offered a detailed account of the ways in which one can possess knowledge and yet not act on it because of lack of control or weakness of will.

LATER GREEK AND ROMAN ETHICS

In ethics, as in many other fields, the later Greek and Roman periods do not display the same penetrating insight as the Classic period of 5th- and 4th-century Greek civilization. Nevertheless, the two dominant schools of thought, Stoicism and Epicureanism, represent important approaches to the question of how one ought to live.

The Stoics. Stoicism had its origins in the views of

Socrates and Plato, as modified by Zeno and then by Chrysippus in the 3rd century BC. It gradually gained influence in Rome, chiefly through the teachings of Cicero (106–43 BC) and then later in the 1st century AD through those of Seneca. Remarkably, its chief proponents include both a slave, Epictetus, and an emperor, Marcus Aurelius. This is a fine illustration of the Stoic message that what is important is the pursuit of wisdom and virtue, a pursuit that is open to all human beings owing to their common capacity for reason and that can be carried out no matter what the external circumstances of their lives.

Today, the word stoic conjures up one who remains unmoved by the sorrows and afflictions that distress the rest of humanity. This is an accurate representation of a stoic ideal, but it must be placed in the context of a systematic approach to life. Plato held that human passions and physical desires are in need of regulation by reason (see above). The Stoics went further: they rejected passions altogether as a basis for deciding what is good or bad. Physical desires cannot simply be abolished, but when we become wise we appreciate the difference between wanting something and judging it to be good. Our desires make us want something, but only our reason can judge the goodness of what is wanted. If we are wise, we will identify with our reason, not with our desires; hence, we will not place our hopes on the attainment of our physical desires nor our anxieties on our failure to attain them. Wise Stoics will feel physical pain as others do, but in their minds they will know that physical pain leaves the true reasoning self untouched. The only thing that is truly good is to live in a state of wisdom and virtue. In aiming at such a life, we are not subject to the same play of fortune that afflicts us when we aim at physical pleasure or material wealth, for wisdom and virtue are matters of the intellect and under our own control. Moreover, if matters become too grim, there is always a way of ending the pain of the physical world. The Stoics were not reluctant to counsel suicide as a means of avoiding otherwise inescapable pain.

Rejection of passion in making moral judgments

Perhaps the most important legacy of Stoicism, however, is its conviction that all human beings share the capacity to reason. This led the Stoics to a fundamental sense of equality, which went beyond the limited Greek conception of equal citizenship. Thus Seneca claimed that the wise man will esteem the community of rational beings far above any particular community in which the accident of birth has placed him, and Marcus Aurelius said that common reason makes all individuals fellow citizens. The belief that human reasoning capacities are common to all was also important, because from it the Stoics drew the implication that there is a universal moral law, which all people are capable of appreciating. The Stoics thus strengthened the tradition that sees the universality of reason as the basis on which ethical relativism is to be rejected.

The Epicureans. While the modern use of the term stoic accurately represents at least a part of the Stoic philosophy, anyone taking the present-day meaning of epicure as a guide to the philosophy of Epicurus (341–270 BC) would go astray. True, the Epicureans regarded pleasure as the sole ultimate good and pain as the sole evil; and they did regard the more refined pleasures as superior, simply in terms of the quantity and durability of the pleasure they provided, to the coarser pleasures. To portray them as searching for these more refined pleasures by dining at the best restaurants and drinking the finest wines, however, is the reverse of the truth. By refined pleasures, Epicurus meant pleasures of the mind, as opposed to the coarse pleasures of the body. He taught that the highest pleasure obtainable is the pleasure of tranquillity, which is to be obtained by the removal of unsatisfied wants. The way to do this is to eliminate all but the simplest wants; these are then easily satisfied even by those who are not wealthy.

The fundamentals of Epicurean ethics

Epicurus developed his position systematically. To determine whether something is good, he would ask if it increased pleasure or reduced pain. If it did, it was good as a means; if it did not, it was not good at all. Thus justice was good but merely as an expedient arrangement to prevent mutual harm. Why not then commit injustice when we can get away with it? Only because, Epicurus says, the perpetual dread of discovery will cause painful anxiety. Epicurus also exalted friendship, and the Epicureans were famous for the warmth of their personal relationships; but, again, they proclaimed that friendship is good only because of its tendency to create pleasure.

Both Stoic and Epicurean ethics can be seen as precursors of later trends in Western ethics: the Stoics of the modern belief in equality and the Epicureans of a Utilitarian ethic based on pleasure. The development of these ethical positions, however, was dramatically affected by the spreading from the East of a new religion that had its roots in a Jewish conception of ethics as obedience to a divine authority. With the conversion of Emperor Constantine I to Christianity by AD 313, the older schools of philosophy lost their sway over the thinking of the Roman Empire.

CHRISTIAN ETHICS FROM THE NEW TESTAMENT TO THE SCHOLASTICS

Ethics in the New Testament. Matthew reports Jesus as having said, in the Sermon on the Mount, that he came not to destroy the law of the prophets but to fulfill it. Indeed, when Jesus is regarded as a teacher of ethics, it is clear that he was more a reformer of the Hebrew tradition than a radical innovator. The Hebrew tradition had a tendency to place great emphasis on compliance with the letter of the law; the Gospel accounts of Jesus portray him as preaching against this "righteousness of the scribes and Pharisees," championing the spirit rather than the letter of the law. This spirit he characterized as one of love, for God and for one's neighbour. But since he was not proposing that the old teachings be discarded, he saw no need to develop a comprehensive ethical system. Christianity thus never really broke with the Jewish conception of morality as a matter of divine law to be discovered by reading and interpreting the word of God as revealed in the Scriptures.

This conception of morality had important consequences for the future development of Western ethics. The Greeks and Romans, and indeed thinkers such as Confucius too, did not have the Western conception of a distinctively moral realm of conduct. For them, everything that one did was a matter of practical reasoning, in which one could do well or poorly. In the more legalistic Judeo-Christian view, however, it is one thing to lack practical wisdom in, say, household budgeting, and a quite different and much more serious matter to fall short of what the moral law requires. This distinction between the moral and the nonmoral realms now affects every question in Western ethics, including the very way the questions themselves are framed.

Another consequence of the retention of the basically legalistic stance of Jewish ethics was that from the beginning Christian ethics had to deal with the question of how to judge the person who breaks the law from good motives or keeps it from bad motives. The latter half of this question was particularly acute because the Gospels describe Jesus as repeatedly warning of a coming resurrection of the dead at which time all would be judged and punished or rewarded according to their sins and virtues in this life. The punishments and rewards were weighty enough to motivate anyone who took this message seriously; and it was given added emphasis by the fact that it was not going to be long in coming. (Jesus said that it would take place during the lifetime of some of those listening to him.) This is, therefore, an ethic that invokes external sanctions as a reason for doing what is right, in contrast to Plato or Aristotle for whom happiness is an internal element of a virtuous life. At the same time, it is an ethic that places love above mere literal compliance with the law. These two aspects do not sit easily together. Can one love God and neighbour in order to be rewarded with eternal happiness in another life?

Basic principles of the Christian ethic

The fact that Jesus and Paul, too, believed in the imminence of the Second Coming led them to suggest ways of living that were scarcely feasible on any other assumption: taking no thought for the morrow; turning the other cheek; and giving away all one has. Even Paul's preference for celibacy rather than marriage and his grudging acceptance of the latter on the basis that "It is better to marry than to burn" makes some sense once we grasp that he was proposing ethical standards for what he thought would be

the last generation on earth. When the expected event did not occur and Christianity became the official religion of the vast and embattled Roman Empire, Christian leaders were faced with the awkward task of reinterpreting these injunctions in a manner more suited for a continuing society.

The new Christian ethical standards did lead to some changes in Roman morality. Perhaps the most vital was a new sense of the equal moral status of all human beings. As previously noted, the Stoics had been the first to elaborate this conception, grounding equality on the common capacity to reason. For Christians, humans are equal because they are all potentially immortal and equally precious in the sight of God. This caused Christians to condemn a wide variety of practices that had been accepted by both Greek and Roman moralists. Many of these related to the taking of innocent human life: from the earliest days Christian leaders condemned abortion, infanticide, and suicide. Even killing in war was at first regarded as wrong, and soldiers converted to Christianity had refused to continue to bear arms. Once the empire became Christian, however, this was one of the inconvenient ideas that had to yield. In spite of what Jesus had said about turning the other cheek, the church leaders declared that killing in a "just war" was not a sin. The Christian condemnation of killing in gladiatorial games, on the other hand, had a more permanent effect. Finally, but perhaps most importantly, while Christian emperors continued to uphold the legality of slavery, the Christian church accepted slaves as equals, admitted them to its ceremonies, and regarded the granting of freedom to slaves as a virtuous, if not obligatory, act. This moral pressure led over several hundred years to the gradual disappearance of slavery in Europe.

The Christian contribution to improving the position of slaves can also be linked with the distinctively Christian list of virtues. Some of the virtues described by Aristotle, as, for example, greatness of soul, are quite contrary in spirit to Christian virtues such as humility. In general, it can be said that the Greeks and Romans prized independence, self-reliance, magnanimity, and worldly success. By contrast, Christians saw virtue in meekness, obedience, patience, and resignation. As the Greeks and Romans conceived virtue, a virtuous slave was almost a contradiction in terms, but for Christians there was nothing in the state of slavery that was incompatible with the highest moral character.

Augustine. Christianity began with a set of scriptures incorporating many ethical injunctions but with no ethical philosophy. The first serious attempt to provide such a philosophy was made by St. Augustine of Hippo (354–430). Augustine was acquainted with a version of Plato's philosophy, and he developed the Platonic idea of the rational soul into a Christian view wherein humans are essentially souls, using their bodies as means to achieve their spiritual ends. The ultimate object remains happiness, as in Greek ethics, but Augustine saw happiness as consisting in a union of the soul with God after the body has died. It was through Augustine, therefore, that Christianity received the Platonic theme of the relative inferiority of bodily pleasures. There was, to be sure, a fundamental difference: whereas Plato saw this inferiority in terms of a comparison with the pleasures of philosophical contemplation in this world, Christians compared them unfavourably with the pleasures of spiritual existence in the next world. Moreover, Christians came to see bodily pleasures not merely as inferior but also as a positive threat to the achievement of spiritual bliss.

It was also important that Augustine could not accept the view, common to so many Greek and Roman philosophers, that philosophical reasoning was the path to wisdom and happiness. For a Christian, of course, the path had to be through love of God and faith in Jesus as the Saviour. The result was to be, for many centuries, a rejection of the use of unfettered reasoning powers in ethics.

Augustine was aware of the tension caused by the dual Christian motivations of love of God and neighbour, on the one hand, and reward and punishment in the afterlife, on the other. He came down firmly on the side of love, insisting that those who keep the moral law through fear of punishment are not really keeping it at all. But it is not ordinary human love, either, that suffices as a motivation for true Christian living. Augustine believed all men bear the burden of Adam's original sin, and so are incapable of redeeming themselves by their own efforts. Only the unmerited grace of God makes possible obedience to the "first greatest commandment" of loving God, and without such, one cannot fulfill the moral law. This view made a clear-cut distinction between Christians and pagan moralists, no matter how humble and pure the latter might be: only the former could be saved because only they could receive the blessing of divine grace. But this gain, as Augustine saw it, was purchased at the cost of denying that man is free to choose good or evil. Only Adam had this choice: he chose for all humanity, and he chose evil.

Aquinas and the moral philosophy of the Scholastics. At this point we may pass over more than 800 years in silence, for there were no major developments in ethics in the West until the rise of Scholasticism in the 12th and 13th centuries. Among the first of the significant works written during this time was a treatise on ethics by the French philosopher and theologian Peter Abelard (1079–1142). His importance in ethical theory lies in his emphasis on intentions. Abelard maintained, for example, that the sin of sexual wrongdoing consists not in the act of illicit sexual intercourse nor even in the desire for it, but in mentally consenting to that desire. In this he was far more modern than Augustine, with his doctrine of grace, and also more thoughtful than those who even today assert that the mere desire for what is wrong is as wrong as the act itself. Abelard saw that there is a problem in holding anyone morally responsible for the existence of mere physical desires. His ingenious solution was taken up by later medieval writers, and traces of it can still be found in modern discussions of moral responsibility.

Aristotle's ethical writings were not known to scholars in western Europe during Abelard's time. Latin translations became available only in the first half of the 13th century, and the rediscovery of Aristotle dominated later medieval philosophy. Nowhere is his influence more marked than in the thought of St. Thomas Aquinas (1225–74), often regarded as the greatest of the Scholastic philosophers and undoubtedly the most influential, since his teachings became the semiofficial philosophy of the Roman Catholic Church. Such is the respect in which Aquinas held Aristotle that he referred to him simply as The Philosopher, and it is not too far from the truth to say that the chief aim of Aquinas' work was to reconcile Aristotle's views with Christian doctrine.

Reconciliation of Aristotelian views with Christian doctrine

Aquinas took from Aristotle the notion of a final end, or *summum bonum*, at which all action is ultimately directed; and, like Aristotle, he saw this end as necessarily linked with happiness. This conception was Christianized, however, by the idea that happiness is to be found in the love of God. Thus a person seeks to know God but cannot fully succeed in this in life on earth. The reward of heaven, where one can know God, is available only to those who merit it, though even then it is given by God's grace rather than obtained by right. Short of heaven, a person can experience only a more limited form of happiness to be gained through a life of virtue and friendship, much as Aristotle had recommended.

The blend of Aristotle's teachings and Christianity is also evident in Aquinas' views about right and wrong, and how we come to know the difference between them. Aquinas is often described as advocating a "natural law" ethic, but this term is easily misunderstood. The natural law to which Aquinas referred does not require a legislator any more than do the laws of nature that govern the motions of the planets. An even more common mistake is to imagine that this conception of natural law relies on contrasting what is natural with what is artificial. Aquinas' theory of the basis of right and wrong developed rather as an alternative to the view that morality is determined simply by the arbitrary will of God. Instead of conceiving of right and wrong in this manner as something fundamentally unrelated to human goals and purposes, Aquinas saw morality as deriving from human nature and the activities that are objectively suited to it.

It is a consequence of this natural law ethic that the difference between right and wrong can be appreciated by the use of reason and reflection on experience. Christian revelation may supplement this knowledge in some respects, but even such pagan philosophers as Aristotle could understand the essentials of virtuous living. We are, however, likely to err when we apply these general principles to the particular cases that confront us in everyday life. Corrupt customs and poor moral education may obscure the messages of natural reason. Hence, societies must enact laws of their own to supplement natural law and, where necessary, to coerce those who, because of their own imperfections, are liable to do what is wrong and socially destructive.

It follows, too, that virtue and human flourishing are linked. When we do what is right, we do what is objectively suited to our true nature. Thus the promise of heaven is no mere external sanction, rewarding actions that would otherwise be indifferent to us or even against our best interests. On the contrary, Aquinas wrote that "God is not offended by us except by what we do against our own good." Reward and punishment in the afterlife reinforce a moral law that all humans, Christian or pagan, have adequate prior reasons for following.

In arguing for his views, Aquinas was always concerned to show that he had the authority of the Scriptures or the Church Fathers on his side, but the substance of his ethical system is to a remarkable degree based on reason rather than revelation. This is strong testimony to the power of Aristotle's example. Nonetheless, Aquinas absorbed the weaknesses as well as the strengths of the Aristotelian system. His attempt to base right and wrong on human nature, in particular, invites the objection that we cannot presuppose our nature to be good. Aquinas might reply that it is good because God made it so, but this merely shifts back one step the issue of the basis of good and bad: Did God make it good in accordance with some independent standard of goodness, or would any human nature made by God be good? If we give the former answer, we need an account of the independent standard of goodness. Because this cannot—if we are to avoid circular argument—be based on human nature, it is not clear what account Aquinas could offer. If we maintain, however, that any human nature made by God would be good, we must accept that if God had made our nature such that we flourish and achieve happiness by torturing the weak and helpless among us, that would have been what we should do in order to live virtuously.

Something resembling this second option—but without the intermediate step of an appeal to human nature—was the position taken by the last of the great Scholastic philosophers, William of Ockham (*c.* 1285–1349). Ockham boldly broke with much that had been taken for granted by his immediate predecessors. Fundamental to this was his rejection of the central Aristotelian idea that all things have a final end, or goal, toward which they naturally tend. He, therefore, also spurned Aquinas' attempt to base morality on human nature, and with it the idea that happiness is man's goal and closely linked with goodness. This led him to a position in stark contrast to almost all previous Western ethics. Ockham denied all standards of good and evil that are independent of God's will. What God wills is good; what God condemns is evil. That is all there is to say about the matter. This position is sometimes called a divine approbation theory, because it defines "good" as whatever is approved by God. As indicated earlier, when discussing attempts to link morality with religion, it follows from such a position that it is meaningless to describe God himself as good. It also follows that if God had willed us to torture children, it would be good to do so. As for the actual content of God's will, according to Ockham, that is not a subject for philosophy but rather a matter for revelation and faith.

Theory of divine approbation

The rigour and consistency of Ockham's philosophy made it for a time one of the leading schools of Scholastic thought, but eventually it was the philosophy of Aquinas that prevailed in the Roman Catholic Church. After the Reformation, however, Ockham's view exerted influence on Protestant theologians. Meanwhile, it hastened the decline of Scholastic moral philosophy because it effectively removed ethics from the sphere of reason.

Renaissance and Reformation

The revival of Classical learning and culture that began in 15th-century Italy and then slowly spread throughout Europe did not give immediate birth to any major new ethical theories. Its significance for ethics lies, rather, in a change of focus. For the first time since the conversion of the Roman Empire to Christianity, man, not God, became the chief object of interest, and the theme was not religion but humanism—the powers, freedom, and accomplishments of human beings. This does not mean that there was a sudden conversion to atheism. Renaissance thinkers remained Christian and still considered human beings as somehow midway between the beasts and the angels. Yet, even this middle position meant that humans were special. It meant, too, a new conception of human dignity and of the importance of the individual.

Machiavelli. Although the Renaissance did not produce any outstanding moral philosophers, there is one writer whose work is of some importance in the history of ethics: the Italian author and statesman Niccolò Machiavelli. His book *Il principe* (1513; *The Prince*) offered advice to rulers as to what they must do to achieve their aims and secure their power. Its significance for ethics lies precisely in the fact that Machiavelli's advice ignores the usual ethical rules: "It is necessary for a prince, who wishes to maintain himself, to learn how not to be good, and to use this knowledge and not use it, according to the necessities of the case." There had not been so frank a rejection of morality since the Greek Sophists. So startling is the cynicism of Machiavelli's advice that it has been suggested that *Il principe* was an attempt to satirize the conduct of the princely rulers of Renaissance Italy. It may be more accurate, however, to view Machiavelli as an early political scientist, concerned only with setting out what human beings are like and how power is maintained, with no intention of passing moral judgment on the state of affairs described. In any case, *Il principe* gained instant notoriety, and Machiavelli's name became synonymous with political cynicism and deviousness. In spite of the chorus of condemnation, the work has led to a sharper appreciation of the difference between the lofty ethical systems of the philosophers and the practical realities of political life.

The first Protestants. It was left to the 17th-century English philosopher and political theorist Thomas Hobbes to take up the challenge of constructing an ethical system on the basis of so unflattering a view of human nature (see below). Between Machiavelli and Hobbes, however, there occurred the traumatic breakup of Western Christianity known as the Reformation. Reacting against the worldly immorality apparent in the Renaissance church, Martin Luther, John Calvin, and other leaders of the new Protestantism sought to return to the pure early Christianity of the Scriptures, especially the teachings of Paul, and of the Church Fathers, with Augustine foremost among them. They were contemptuous of Aristotle (Luther called him a "buffoon") and of non-Christian philosophers in general. Luther's standard of right and wrong was what God commands. Like William of Ockham, Luther insisted that the commands of God cannot be justified by any independent standard of goodness: good simply means what God commands. Luther did not believe these commands would be designed to satisfy human desires because he was convinced that desires are totally corrupt. In fact, he thought that human nature was totally corrupt. In any case, Luther insisted that one does not earn salvation by good works: one is justified by faith in Christ and receives salvation through divine grace.

Luther's standard of right and wrong

It is apparent that if these premises are accepted, there is little scope for human reason in ethics. As a result, no moral philosophy has ever had the kind of close association with any Protestant church that, say, the philosophy of Aquinas has had with Roman Catholicism. Yet, because Protestants emphasized the capacity of the individual to read and understand the Gospels without obtaining the authoritative interpretation of the church, the ultimate outcome of the Reformation was a greater freedom to

read and write independently of the church hierarchy. This made possible a new era of ethical thought.

From this time, too, distinctively national traditions of moral philosophy began to emerge; the British tradition, in particular, developed largely independently of ethics on the Continent. Accordingly, the present discussion will follow this tradition through the 19th century before returning to consider the different line of development in continental Europe.

THE BRITISH TRADITION: FROM HOBBES TO THE UTILITARIANS

Hobbes. Thomas Hobbes (1588–1679) is an outstanding example of the independence of mind that became possible in Protestant countries after the Reformation. God does, to be sure, play an honourable role in Hobbes's philosophy, but it is a dispensable role. The philosophical edifice stands on its own foundations; God merely crowns the apex. Hobbes was the equal of the Greek philosophers in his readiness to develop an ethical position based only on the facts of human nature and the circumstances in which humans live; and he surpassed even Plato and Aristotle in the extent to which he sought to do this by systematic deduction from clearly set out premises.

The psychological hedonism of Hobbes

Hobbes started with a severe view of human nature: all of man's voluntary acts are aimed at self-pleasure or self-preservation. This position is known as psychological hedonism, because it asserts that the fundamental psychological motivation is the desire for pleasure. Like later psychological hedonists, Hobbes was confronted with the objection that people often seem to act altruistically. There is a story that Hobbes was seen giving alms to a beggar outside St. Paul's Cathedral. A clergyman sought to score a point by asking Hobbes if he would have given the money, had Christ not urged giving to the poor. Hobbes replied that he gave the money because it pleased him to see the poor man pleased. The reply reveals the dilemma that always faces those who propose startling new explanations for all human actions: either the theory is flagrantly at odds with how people really behave or else it must be broadened to such an extent that it loses much of what made it so shocking in the first place.

Hobbes's account of "good" is equally devoid of religious or metaphysical premises. He defined good as "any object of desire," and insisted that the term must be used in relation to a person—nothing is simply good of itself independently of the person who desires it. Hobbes may therefore be considered a subjectivist. If one were to say, for example, of the incident just described, "What Hobbes did was good," this statement would not be objectively true or false. It would be good for the poor man, and, if Hobbes's reply was accurate, it would also be good for Hobbes. But if a second poor person, for instance, was jealous of the success of the first, that person could quite properly say that what Hobbes did was bad.

Remarkably, this unpromising picture of self-interested individuals who have no notion of good apart from their own desires serves as the foundation of Hobbes's account of justice and morality in his masterpiece, *Leviathan* (1651). Starting with the premises that humans are self-interested and the world does not provide for all their needs, Hobbes argued that in the state of nature, without civil society, there will be competition between men for wealth, security, and glory. The ensuing struggle is Hobbes's famous "war of all against all," in which there can be no industry, commerce, or civilization, and the life of man is "solitary, poor, nasty, brutish and short." The struggle occurs because each individual rationally pursues his or her own interests, but the outcome is in no one's interest.

How can this disastrous situation be ended? Not by an appeal to morality or justice; in the state of nature these ideas have no meaning. Yet, we want to survive and we can reason. Our reason leads us to seek peace if it is attainable but to continue to use all the means of war if it is not. How is peace to be obtained? Only by a social contract. We must all agree to give up our rights to attack others in return for their giving up their rights to attack us. By reasoning in order to increase our prospects for survival, we have found the solution.

We know that a social contract will solve our problems. Our reason therefore leads us to desire such an arrangement. But how is it to come about? My reason cannot tell me to accept it while others do not. Nor is Hobbes under the illusion that the mere making of a promise or contract will carry any weight. Since we are self-interested, we will keep our promises only if it is in our interest to do so. A promise that cannot be enforced is worthless. Therefore, in making the social contract, we must establish some means of enforcing it. To do this we must all hand our powers over to some other person or group of persons who will punish anyone who breaches the contract. This person or group of persons Hobbes calls the sovereign. It may be a single person, or an elected legislature, or almost any other form of government; the essence of sovereignty consists only in having sufficient power to keep the peace by punishing those who would break it. When such a sovereign—the Leviathan of his title—exists, justice becomes meaningful in that agreements or promises are necessarily kept. At the same time, each individual has adequate reason to be just, for the sovereign will ensure that those who do not keep their agreements are suitably punished.

Hobbes witnessed the turbulence and near anarchy of the English Civil Wars (1642–51) and was keenly aware of the dangers caused by disputed sovereignty. His solution was to insist that sovereignty must not be divided. Because the sovereign was appointed to enforce the social contract fundamental to peace and everything desired, it can only be rational to resist the sovereign if the sovereign directly threatens one's life. Hobbes was, in effect, a supporter of absolute sovereignty, and this has been the focus of much political discussion of his ideas. His significance for ethics, however, lies rather in his success in dealing with the subject independently of theology and of those quasi-theological or quasi-Aristotelian accounts that see the world as designed for the benefit of human beings. With this achievement, he brought ethics into the modern era.

Early intuitionists: Cudworth, More, and Clarke. There was, of course, immediate opposition to Hobbes's views. Ralph Cudworth (1617–88), one of a group known as the Cambridge Platonists, defended a position in some respects similar to that of Plato. That is to say, Cudworth believed the distinction between good and evil does not lie in human desires but is something objective and can be known by reason, just as the truths of mathematics can be known by reason. Cudworth was thus a forerunner of what has since come to be called intuitionism, the view that there are objective moral truths that can be known by a kind of rational intuition. This view was to attract the support of a line of distinguished thinkers until the 20th century when it became for a time the dominant view in British academic philosophy.

Henry More (1614–87), another leading member of the Cambridge Platonists, attempted to give effect to the comparison between mathematics and morality by listing moral axioms that can be seen as self-evidently true, just as the axioms of geometry are seen to be self-evident. In marked contrast to Hobbes, More included an axiom of benevolence: "If it be good that one man should be supplied with the means of living well and happily, it is mathematically certain that it is doubly good that two should be so supplied, and so on." Here, More was attempting to build on something that Hobbes himself accepted—namely, our own desire to be supplied with the means of living well. More, however, wanted to enlist reason to lead us beyond this narrow egoism to a universal benevolence. There are traces of this line of thought in the Stoics, but it was More who introduced it into British ethical thinking, wherein it is still very much alive.

More's axiom of benevolence

Samuel Clarke (1675–1729), the next major intuitionist, accepted More's axiom of benevolence in slightly different words. He was also responsible for a principle of equity, which, though derived from the Golden Rule so widespread in ancient ethics, was formulated with a new precision: "Whatever I judge reasonable or unreasonable for another to do for me, that by the same judgment I declare reasonable or unreasonable that I in the like case should do for him." As for the means by which these moral truths are known, Clarke accepted Cudworth's and

More's analogy with truths of mathematics and added the idea that what human reason discerns is a certain "fitness or unfitness" about the relationship between circumstances and actions. The right action in a given set of circumstances is the fitting one; the wrong action is unfitting. This is something known intuitively; it is self-evident.

Clarke's notion of fitness is obscure, but intuitionism faces a still more serious problem that has always been a barrier to its acceptance. Suppose we accept the ability of reason to discern that it would be wrong to deceive a person in order to profit from the deception. Why should our discerning this truth provide us with a motive sufficient to override our desire to profit? The intuitionist position divorces our moral knowledge from the forces that motivate us. The former is a matter of reason, the latter of desire.

The punitive power of Hobbes's sovereign is, of course, one way to provide sufficient motivation for obedience to the social contract and to the laws decreed by the sovereign as necessary for the peaceful functioning of society. The intuitionists, however, wanted to show that morality is objective and holds in all circumstances whether there is a sovereign or not. Reward and punishment in the afterlife, administered by an all-powerful God, would provide a more universal motive; and some intuitionists, such as Clarke, did make use of this divine sanction. Other thinkers, however, wanted to show that it is reasonable to do what is good independently of the threats of any external power, human or divine. This desire lay behind the development of the major alternative to intuitionism in 17th- and 18th-century British moral philosophy: moral sense theory. The debate between the intuitionist and moral sense schools of thought aired for the first time the major issue in what is still the central debate in moral philosophy: Is morality based on reason or on feelings?

Shaftesbury and the moral sense school. The term moral sense was first used by the 3rd Earl of Shaftesbury (1671–1713), whose writings reflect the optimistic tone both of the school of thought he founded and of so much of the philosophy of the 18th-century Enlightenment. Shaftesbury believed that Hobbes had erred by presenting a one-sided picture of human nature. Selfishness is not the only natural passion. We also have natural feelings directed to others: benevolence, generosity, sympathy, gratitude, and so on. These feelings give us an "affection for virtue," which leads us to promote the public interest. Shaftesbury called this affection the moral sense, and he thought it created a natural harmony between virtue and self-interest. Shaftesbury was, of course, realistic enough to acknowledge that we also have contrary desires and that not all of us are virtuous all of the time. Virtue could, however, be recommended because—and here Shaftesbury picked up a theme of Greek ethics—the pleasures of virtue are superior to the pleasures of vice.

Harmony between virtue and self-interest through moral sense

Butler on self-interest and conscience. Joseph Butler (1692–1752), a bishop of the Church of England, developed Shaftesbury's position in two ways. He strengthened the case for a harmony between morality and enlightened self-interest by claiming that happiness occurs as a by-product of the satisfaction of desires for things other than happiness itself. Those who aim directly at happiness do not find it; those who have their goals elsewhere are more likely to achieve happiness as well. Butler was not doubting the reasonableness of pursuing one's own happiness as an ultimate aim. He went so far as to say that "... when we sit down in a cool hour, we can neither justify to ourselves this or any other pursuit, till we are convinced that it will be for our happiness, or at least not contrary to it." He held, however, that direct and simple egoism is a self-defeating strategy. Egoists will do better for themselves by adopting immediate goals other than their own interests and living their everyday life in accordance with these more immediate goals.

Conscience as a rational guide to conduct

Butler's second addition to Shaftesbury's account was the idea of conscience. This he saw as a second natural guide to conduct, alongside enlightened self-interest. Butler believed that there is no inconsistency between the two; he admitted, however, that skeptics may doubt "the happy tendency of virtue" and for them conscience can serve as an authoritative guide. Just what reason these skeptics have to follow conscience, if they believe its guidance to be contrary to their own happiness, is something that Butler did not adequately explain. Nevertheless, his introduction of conscience as an independent source of moral reasoning reflects an important difference between ancient and modern ethical thinking. The Greek and Roman philosophers would have had no difficulty in accepting everything Butler said about the pursuit of happiness, but they would not have understood his idea of another independent source of rational guidance. Although Butler insisted that the two operate in harmony, this was for him a fortunate fact about the world and not a necessary principle of reason. Thus his recognition of conscience opened the way for later formulations of a universal principle of conduct at odds with the path indicated by even the most enlightened self-interested reasoning.

The climax of moral sense theory: Hutcheson and Hume. The moral sense school reached its fullest development in the works of two Scottish philosophers, Francis Hutcheson (1694–1746) and David Hume (1711–76). Hutcheson was concerned with showing, against the intuitionists, that moral judgment cannot be based on reason and therefore must be a matter of whether an action is "amiable or disagreeable" to one's moral sense. Like Butler's notion of conscience, Hutcheson's moral sense does not find pleasing only, or even predominantly, those actions that are in one's own interest. On the contrary, Hutcheson conceived moral sense as based on a disinterested benevolence. This led him to state, as the ultimate criterion of the goodness of an action, a principle that was to serve as the basis for the Utilitarian reformers: "that action is best which procures the greatest happiness for the greatest numbers . . . ."

Hume, like Hutcheson, held that reason cannot be the basis of morality. His chief ground for this conclusion was that morality is essentially practical: there is no point in judging something good if the judgment does not incline us to act accordingly. Reason alone, however, Hume regarded as "the slave of the passions." Reason can show us how best to achieve our ends, but it cannot determine our ultimate desires and is incapable of moving us to action except in accordance with some prior want or desire. Hence, reason cannot give rise to moral judgments.

This is an important argument that is still employed in the debate between those who believe that morality is based on reason and those who base it instead on emotion or feelings. Hume's conclusion certainly follows from his premises. Can either premise be denied? We have seen that intuitionists such as Cudworth and Clarke maintained that reason can lead to action. Reason, they would have said, leads us to see a particular action as fitting in given circumstances and therefore to do it. Hume would have none of this. "Tis not contrary to reason," he provocatively asserted, "to prefer the destruction of the whole world to the scratching of my finger." To show that he was not embracing the view that only egoism is rational, Hume continued: "Tis not contrary to reason to choose my total ruin, to prevent the least uneasiness of an Indian or person wholly unknown to me." His point was simply that to have these preferences is to have certain desires or feelings; they are not matters of reason at all. The intuitionists might insist that moral and mathematical reasoning are analogous, but this analogy was not helpful here. We can know a truth of geometry and not be motivated to act in any way.

What of Hume's other premise that morality is essentially practical and moral judgments must lead to action? This can be denied more easily. We could say that moral judgments merely tell us what is right or wrong. They do not lead to action unless we want to do what is right. Then Hume's argument would do nothing to undermine the claim that moral judgments are based on reason. But there is a price to pay. The terms right and wrong lose much of their force. We can no longer assert that those who know what is right but do what is wrong are in any way irrational. They are just people who do not happen to have the desire to do what is right. This desire—because it leads to action—must be acknowledged to be based on feeling rather than reason. Denying that morality is necessarily action-guiding means abandoning the idea, so important

to those defending the objectivity of morality, that some things are objectively required of all rational beings.

Hume's forceful presentation of this argument against a rational basis for morality would have been enough to earn him a place in the history of ethics, but it is by no means his only achievement in this field. In *A Treatise of Human Nature* (1739–40) Hume points, almost as an afterthought, to the fact that writers on morality regularly start by making various observations about human nature or about the existence of a god—all statements of fact about what is the case—and then suddenly switch to statements about what ought or ought not be done. Hume says that he cannot conceive how this new relationship of "ought" can be deduced from the preceding statements that were related by "is"; and he suggests these authors should explain how this deduction is to be achieved. The point has since been called Hume's Law and taken as proof of the existence of a gulf between facts and values, or between "is" and "ought." This places too much weight on Hume's brief and ironic comment, but there is no doubt that many writers, both before and after Hume, have argued as if values could easily be deduced from facts. They can usually be found to have smuggled values in somewhere. Attention to Hume's Law makes it easy for us to detect such logically illicit contraband.

Hume's Law

Hume's positive account of morality is in line with that of the moral sense school: "The hypothesis which we embrace is plain. It maintains that morality is determined by sentiment. It defines virtue to be whatever mental action or quality gives to a spectator the pleasing sentiment of approbation; and vice the contrary." In other words, Hume takes moral judgments to be based on a feeling. They do not reflect any objective state of the world. Having said that, however, it may still be asked whether this feeling is one that is common to all of us or one that varies from individual to individual. If Hume gives the former answer, moral judgments retain a kind of objectivity. While they do not reflect anything out there in the universe apart from human feelings, one's judgments may be true or false depending on whether they capture this universal human moral sentiment. If, on the other hand, the feeling varies from one individual to the next, moral judgments become entirely subjective. People's judgments would express their own feelings, and to reject someone else's judgment as wrong would merely be to say that one's own feelings were different.

Hume does not make entirely clear which of these two views he holds; but if he is to avoid breaching his own rule about not deducing an "ought" from an "is," he cannot hold that a moral judgment can follow logically from a description of the feelings that an action gives to a particular group of spectators. From the mere existence of a feeling we cannot draw the inference that we ought to obey it. For Hume to be consistent on this point—and even with his central argument that moral judgments must move to action—the moral judgment must be based not on the fact that all people, or most people, or even the speaker, have a certain feeling; it must rather be based on the actual experience of the feeling by whoever accepts the judgment. This still leaves it open whether the feeling is common to all or limited to the person accepting the judgment, but it shows that, in either case, the "truth" of a judgment for any individual depends on whether that individual actually has the appropriate feeling. Is this "truth" at all? As will be seen below, 20th-century philosophers with views broadly similar to Hume's have suggested that moral judgments have a special kind of meaning not susceptible of truth or falsity in the ordinary way.

The intuitionist response: Price and Reid. Powerful as they were, Hume's arguments did not end the debate between the moral sense theorists and the intuitionists. They did, however, lead Richard Price (1723–91), Thomas Reid (1710–96), and later intuitionists to abandon the idea that moral truths can be established by some process of demonstrative reasoning akin to that used in mathematics. Instead, these proponents of intuitionism took the line that our notions of right and wrong are simple, objective ideas, directly perceived by us and not further analyzable into anything such as "fitness." We know of these ideas, not through any moral sense based on feelings, but rather through a faculty of reason or of the intellect that is capable of discerning truth. Since Hume, this has been the only plausible form of intuitionism. Yet, Price and Reid failed to explain adequately just what are the objective moral qualities that we perceive directly and how they connect with the actions we choose.

Utilitarianism. At this point the argument over whether morality is based on reason or feelings was temporarily exhausted, and the focus of British ethics shifted from such questions about the nature of morality as a whole to an inquiry into which actions are right and which are wrong. Today, the distinction between these two types of inquiry would be expressed by saying that whereas the 18th-century debate between intuitionism and the moral sense school dealt with questions of metaethics, 19th-century thinkers became chiefly concerned with questions of normative ethics. The positions we take in metaethics over whether ethics is objective or subjective, for example, do not tell us what we ought to do. That task is the province of normative ethics.

Paley. The impetus to the discussion of normative ethics was provided by the challenge of Utilitarianism. The essential principle of Utilitarianism was, as noted above, put forth by Hutcheson. Curiously, it gained further development from the widely read theologian William Paley (1743–1805), who provides a good example of the independence of metaethics and normative ethics. His position on the nature of morality was similar to that of Ockham and Luther—namely, he held that right and wrong are determined by the will of God. Yet, because he believed that God wills the happiness of his creatures, his normative ethics were Utilitarian: whatever increases happiness is right; whatever diminishes it is wrong.

Bentham. Notwithstanding these predecessors, Jeremy Bentham (1748–1832) is properly considered the father of modern Utilitarianism. It was he who made the Utilitarian principle serve as the basis for a unified and comprehensive ethical system that applies, in theory at least, to every area of life. Never before had a complete, detailed system of ethics been so consistently constructed from a single fundamental ethical principle.

Bentham as the father of modern Utilitarianism

Bentham's ethics began with the proposition that nature has placed human beings under two masters: pleasure and pain. Anything that seems good must either be directly pleasurable, or thought to be a means to pleasure or to the avoidance of pain. Conversely, anything that seems bad must either be directly painful, or thought to be a means to pain or to the deprivation of pleasure. From this Bentham argued that the words right and wrong can only be meaningful if they are used in accordance with the Utilitarian principle, so that whatever increases the net surplus of pleasure over pain is right and whatever decreases it is wrong.

Bentham then set out how we are to weigh the consequences of an action, and thereby decide whether it is right or wrong. We must, he says, take account of the pleasures and pains of everyone affected by the action, and this is to be done on an equal basis: "Each to count for one, and none for more than one." (At a time when Britain had a major trade in slaves, this was a radical suggestion; and Bentham went further still, explicitly extending consideration to nonhuman animals as well.) We must also consider how certain or uncertain the pleasures and pains are, their intensity, how long they last, and whether they tend to give rise to further feelings of the same or of the opposite kind.

Bentham did not allow for distinctions in the quality of pleasure or pain as such. Referring to a popular game, he affirmed that "quantity of pleasure being equal, pushpin is as good as poetry." This led his opponents to characterize his philosophy as one fit for pigs. The charge is only half true. Bentham could have defended a taste for poetry on the grounds that whereas one tires of mere games, the pleasures of a true appreciation of poetry have no limit; thus the quantities of pleasure obtained by poetry are greater than those obtained by pushpin. All the same, one of the strengths of Bentham's position is its honest bluntness, which it owes to his refusal to be fazed by the

contrary opinions either of conventional morality or of refined society. He never thought that the aim of Utilitarianism was to explain or justify ordinary moral views; it was, rather, to reform them.

Mill. John Stuart Mill (1806–73), Bentham's successor as the leader of the Utilitarians and the most influential British thinker of the 19th century, had some sympathy for the view that Bentham's position was too narrow and crude. His essay "Utilitarianism" (1861) introduced several modifications, all aimed at a broader view of what is worthwhile in human existence and at implications less shocking to established moral convictions. Although his position was based on the maximization of happiness (and this is said to consist in pleasure and the absence of pain), he distinguished between pleasures that are higher and those that are lower in quality. This enabled him to say that it is "better to be Socrates dissatisfied than a fool satisfied." The fool, he argued, would only be of a different opinion because he did not know both sides of the question.

Mill sought to show that Utilitarianism is compatible with moral rules and principles relating to justice, honesty, and truthfulness by arguing that Utilitarians should not attempt to calculate before each action whether that specific action will maximize utility. Instead, they should be guided by the fact that an action falls under a general principle (such as the principle that we should keep our promises), and adherence to that general principle tends to increase happiness. Only under special circumstances is it necessary to consider whether an exception may have to be made.

Sidgwick. Mill's easily readable prose ensured a wide audience for his exposition of Utilitarianism, but as a philosopher he was markedly inferior to the last of the 19th-century Utilitarians, Henry Sidgwick (1838–1900). Sidgwick's *Methods of Ethics* (1874) is the most detailed and subtle work of Utilitarian ethics yet produced. Especially noteworthy is his discussion of the various principles accepted by what he calls common sense morality—*i.e.,* the morality accepted by most people without systematic thought. Price, Reid, and some adherents of their brand of intuitionism thought that such principles (*e.g.,* those of truthfulness, justice, honesty, benevolence, purity, and gratitude) were self-evident, independent moral truths. Sidgwick was himself an intuitionist as far as the basis of ethics was concerned: he believed that the principle of Utilitarianism must ultimately be based on a self-evident axiom of rational benevolence. Nonetheless, he strongly rejected the view that all principles of common sense morality are themselves self-evident. He went on to demonstrate that the allegedly self-evident principles conflict with one another and are vague in their application. They could only be part of a coherent system of morality, he argued, if they were regarded as subordinate to the Utilitarian principle, which defined their application and resolved the conflicts between them.

Attempt at reconciling common sense morality and Utilitarianism

Sidgwick was satisfied that he had reconciled common sense morality and Utilitarianism by showing that whatever was sound in the former could be accounted for by the latter. He was, however, troubled by his inability to achieve any such reconciliation between Utilitarianism and egoism, the third method of ethical reasoning dealt with in his book. True, Sidgwick regarded it as self-evident that "from the point of view of the universe" one's own good is of no greater value than the like good of any other person, but what could be said to the egoist who expresses no concern for the point of view of the universe, taking his stand instead on the fact that his own good mattered more to him than anyone else's? Bentham had apparently believed either that self-interest and the general happiness are not at odds or that it is the legislator's task to reward or punish actions so as to see that they are not. Mill also had written of the need for sanctions but was more concerned with the role of education in shaping human nature in such a way that one finds happiness in doing what benefits all. By contrast, Sidgwick was convinced that this could lead at best to a partial overlap between what is in one's own interest and what is in the interest of all. Hence, he searched for arguments with which to convince the egoist of the rationality of universal benevolence but failed to find any. *The Methods of Ethics* concludes with an honest admission of this failure and an expression of dismay at the fact that, as a result, ". . . it would seem necessary to abandon the idea of rationalizing [morality] completely."

THE CONTINENTAL TRADITION: FROM SPINOZA TO NIETZSCHE

Spinoza. If Hobbes is to be regarded as the first of a distinctively British philosophical tradition, the Dutch-Jewish philosopher Benedict Spinoza (1632–77) appropriately occupies the same position in continental Europe. Unlike Hobbes, Spinoza did not provoke a long-running philosophical debate. In fact, his philosophy was neglected for a century after his death and was in any case too much of a self-contained system to invite debate. Nevertheless, Spinoza held positions on crucial issues that were in sharp contrast to those taken by Hobbes, and these differences were to grow over the centuries during which British and continental European philosophy followed their own paths.

The first of these contrasts with Hobbes is Spinoza's attitude toward natural desires. As has been noted, Hobbes took self-interested desire for pleasure as an unchangeable fact about human nature and proceeded to build a moral and political system to cope with it. Spinoza did just the opposite. He saw natural desires as a form of bondage. We do not choose to have them of our own will. Our will cannot be free if it is subject to forces outside itself. Thus our real interests lie not in satisfying these desires but in transforming them by the application of reason. Spinoza thus stands in opposition not only to Hobbes but also to the position later to be taken by Hume, for Spinoza saw reason not as the slave of the passions but as their master.

The second important contrast is that while individual humans and their separate interests are always assumed in Hobbes's philosophy, this separation is simply an illusion from Spinoza's viewpoint. Everything that exists is part of a single system, which is at the same time nature and God. (One possible interpretation of this is that Spinoza was a pantheist, believing that God exists in every aspect of the world and not apart from it.) We, too, are part of this system and are subject to its rationally necessary laws. Once we know this, we understand how irrational it would be to desire that things should be different from the way they are. This means that it is irrational to envy, to hate, and to feel guilt, for these emotions presuppose the possibility of things being different. So we cease to feel such emotions and find peace, happiness, and even freedom—in Spinoza's terms the only freedom there can be—in understanding the system of which we are a part.

A view of the world so different from our everyday conceptions as that of Spinoza's cannot be made to seem remotely plausible when presented in summary form. To many philosophers it remains implausible even when complete. Its value for ethics, however, lies not in its validity as a whole, but in the introduction into continental European philosophy of a few key ideas: that our everyday nature may not be our true nature; that we are part of a larger unity; and that freedom is to be found in following reason.

Leibniz. The German philosopher and mathematician Gottfried Wilhelm Leibniz (1646–1716), the next great figure in the Rationalist tradition, gave scant attention to ethics, perhaps because of his belief that the world is governed by a perfect God, and hence must be the best of all possible worlds. As a result of Voltaire's hilarious parody in *Candide* (1758), this position has achieved a certain notoriety. It is not generally recognized, however, that it does at least provide a consistent solution to a problem that has baffled thinking Christians for many centuries: How can there be evil in a world governed by an all-powerful, all-knowing, and all-good God? Leibniz's solution may not be plausible, but there may be no better one if the above premises are allowed to pass unchallenged.

Rousseau. It was the French philosopher and writer Jean-Jacques Rousseau (1712–78) who took the next step. His *Discours sur l'origine et les fondements de l'inégalité parmi les hommes* (1755; *A Discourse upon the Origin and*

Foundation of the Inequality Among Mankind) depicted a state of nature very different from that described by Hobbes as well as from Christian conceptions of original sin. Rousseau's "noble savages" lived isolated, trouble-free lives, supplying their simple wants from the abundance that nature provided and even coming to each other's aid in times of need. Only when someone claimed possession of a piece of land did laws have to be introduced, and with them came civilization and all its corrupting influences. This is, of course, a message that resembles one of Spinoza's key points: The human nature we see before us in our fellow citizens is not the only possibility; somewhere, there is something better. If we can find a way to reach it, we will have found the solution to our ethical and social problems.

Rousseau revealed his route in his *Contrat social* (1762; *A Treatise on the Social Compact*, or *Social Contract*). It required rule by the "general will." This may sound like democracy and, in a sense, it was democracy that Rousseau advocated; but his conception of rule by the general will is very different from the modern idea of democratic government. Today, we assume that in any society the interests of different citizens will be in conflict, and that as a result for every majority that succeeds in having its will implemented there will be a minority that fails to do so. For Rousseau, on the other hand, the general will is not the sum of all the individual wills in the community but the true common will of all the citizens. Even if a person dislikes and opposes a decision carried by the majority, that decision represents the general will, the common will in which he shares. For this to be possible, Rousseau must be assuming that there is some common good in which all human beings share and hence that their true interests coincide. As man passes from the state of nature to civil society, he has to "consult his reason rather than study his inclinations." This is not, however, a sacrifice of his true interests, for in following reason he ceases to be a slave to "physical impulses" and so gains moral freedom.

Rousseau's notion of general will

This leads to a picture of civilized human beings as divided selves. The general will represents the rational will of every member of the community. If an individual opposes the decision of the general will, his opposition must stem from his physical impulses and not from his true, autonomous will. For obvious reasons, this idea was to find favour with such autocratic leaders of the French Revolution as Robespierre. It also had a much less sinister influence on one of the outstanding philosophers of modern times: Immanuel Kant of Germany.

Kant. Interestingly, Kant (1724–1804) acknowledged that he had despised the ignorant masses until he read Rousseau and came to appreciate the worth that exists in every human being. For other reasons too, Kant is part of the tradition deriving from both Spinoza and Rousseau. Like his predecessors, Kant insisted that actions resulting from desires cannot be free. Freedom is to be found only in rational action. Moreover, whatever is demanded by reason must be demanded of all rational beings; hence, rational action cannot be based on a single individual's personal desires, but must be action in accordance with something that he can will to be a universal law. This view roughly parallels Rousseau's idea of the general will as that which, as opposed to the individual will, a person shares with the whole community. Kant extended this community to all rational beings.

Kant's most distinctive contribution to ethics was his insistence that our actions possess moral worth only when we do our duty for its own sake. He first introduced this idea as something accepted by our common moral consciousness and only then tried to show that it is an essential element of any rational morality. In claiming that this idea is central to the common moral consciousness, Kant was expressing in heightened form a tendency of Judeo-Christian ethics and revealing how much the Western ethical consciousness had changed since the time of Socrates, Plato, and Aristotle.

Does our common moral consciousness really insist that there is no moral worth in any action done for any motive other than duty? Certainly we would be less inclined to praise the young man who plunges into the surf to rescue a drowning child if we learned that he did it because he expected a handsome reward from the child's millionaire father. This feeling lies behind Kant's disagreement with all those moral philosophers who have argued that we should do what is right because that is the path to happiness, either on earth or in heaven. But Kant went further than this. He was equally opposed to those who see benevolent or sympathetic feelings as the basis of morality. Here he may be reflecting the moral consciousness of 18th-century Protestant Germany, but it appears that even then the moral consciousness of Britain, as reflected in the writings of Shaftesbury, Hutcheson, Butler, and Hume, was very different. The moral consciousness of Western civilization in the last quarter of the 20th century also appears to be different from the one Kant was describing.

Kant's ethics is based on his distinction between hypothetical and categorical imperatives. He called any action based on desires a hypothetical imperative, meaning by this that it is a command of reason that applies only if we desire the goal. For example, "Be honest, so that people will think well of you!" is an imperative that applies only if you want people to think well of you. A similarly hypothetical analysis can be given of the imperatives suggested by, say, Shaftesbury's ethics: "Help those in distress, if you sympathize with their sufferings!" In contrast to such approaches to ethics, Kant said that the commands of morality must be categorical imperatives: they must apply to all rational beings, regardless of their wants and feelings. To most philosophers this poses an insuperable problem: a moral law that applied to all rational beings, irrespective of their personal wants and desires, could have no specific goals or aims because all such aims would have to be based on someone's wants or desires. It took Kant's peculiar genius to seize upon precisely this implication, which to others would have refuted his claims, and to use it to derive the nature of the moral law. Because nothing else but reason is left to determine the content of the moral law, the only form this law can take is the universal principle of reason. Thus the supreme formal principle of Kant's ethics is: "Act only on that maxim through which you can at the same time will that it should become a universal law."

The dictates of morality as categorical imperatives

Kant still faced two major problems. First, he had to explain how we can be moved by reason alone to act in accordance with this supreme moral law; and, second, he had to show that this principle is able to provide practical guidance in our choices. If we were to couple Hume's theory that reason is always the slave of the passions with Kant's denial of moral worth to all actions motivated by desires, the outcome would be that no actions can have moral worth. To avoid such moral skepticism, Kant maintained that reason alone can lead to action. Unfortunately he was unable to say much in defense of this claim. Of course, the mere fact that we otherwise face so unpalatable a conclusion is in itself a powerful incentive to believe that somehow a categorical imperative must be possible, but this is not convincing to anyone not already wedded to Kant's view of moral worth. At one point Kant appeared to be taking a different line. He wrote that the moral law inevitably produces in us a feeling of reverence or awe. If he meant to say that this feeling then becomes the motivation for obedience, however, he was conceding Hume's point that reason alone is powerless to bring about action. It would also be difficult to accept that anything, even the moral law, can necessarily produce a certain kind of feeling in all rational beings regardless of their psychological constitution. Thus this approach does not succeed in clarifying Kant's position or rendering it plausible.

Kant gave closer attention to the problem of how his supreme formal principle of morality can provide guidance in concrete situations. One of his examples is as follows. Suppose that I plan to get some money by promising to pay it back, although I have no intention of keeping my promise. The maxim of such an action might be "Make false promises when it suits you to do so." Could such a maxim be a universal law? Of course not. If promises were so easily broken, no one would rely on them, and the practice of promising would cease. For this reason,

I know that the moral law does not allow me to carry out my plan.

Not all situations are so easily decided. Another of Kant's examples deals with aiding those in distress. I see someone in distress, whom I could easily help, but I prefer not to do so. Can I will as a universal law the maxim that a person should refuse assistance to those in distress? Unlike the case of promising, there is no strict inconsistency in this maxim being a universal law. Kant, however, says that I cannot will it to be such because I may someday be in distress myself, and I would then want assistance from others. This type of example is less convincing than the previous one. If I value self-sufficiency so highly that I would rather remain in distress than escape from it through the intervention of another, Kant's principle no longer tells me that I have a duty to assist those in distress. In effect, Kant's supreme principle of practical reason can only tell us what to do in those special cases in which turning the maxim of our action into a universal law yields a contradiction. Outside this limited range, the moral law that was to apply to all rational beings regardless of their wants and desires cannot guide us except by appealing to our desires.

Kant does offer alternative formulations of the categorical imperative, and one of these has been seen as providing more substantial guidance than the formulation so far considered. This formulation is: "So act that you treat humanity in your own person and in the person of everyone else always at the same time as an end and never merely as means." The connection between this formulation and the first one is not entirely clear, but the idea seems to be that when I choose for myself I treat myself as an end. If, therefore, in accordance with the principle of universal law, I must choose so that all could choose similarly, I must respect everyone else as an end. Even if this is valid, the application of the principle raises further questions. What is it to treat someone merely as a means? Using a person as a slave is an obvious example; Kant, like Bentham, was making a stand against this kind of inequality while it still flourished as an institution in some parts of the world. But to condemn slavery we have only to give equal weight to the interests of the slaves. Does Kant's principle take us any further than Utilitarianism? Modern Kantians hold that it does because they interpret it as denying the legitimacy of sacrificing the rights of one human being in order to benefit others.

The deontological nature of Kant's ethics

One thing that can be said confidently is that Kant was firmly opposed to the Utilitarian principle of judging every action by its consequences. His ethics is a deontology. In other words, the rightness of an action depends on whether it accords with a rule irrespective of its consequences. In one essay Kant went so far as to say that it would be wrong to tell a lie even to a would-be murderer who came to your door seeking to kill an innocent person hidden in your house. This kind of situation illustrates how difficult it is to remain a strict deontologist when principles may clash. Apparently Kant believed that his principle of universal law required that one never tell lies, but it could also be argued that his principle of treating everyone as an end would necessitate doing everything possible to save the life of an innocent person. Another possibility would be to formulate the maxim of the action with sufficient precision to define the circumstances under which it would be permissible to tell lies—*e.g.*, we could all agree to a universal law that permitted lies to people intending to commit murder. Kant did not explore such solutions.

Hegel. Kant's philosophy deeply affected subsequent German thought, but there were several aspects of it that troubled later thinkers. One of these was his portrayal of human nature as irreconcilably split between reason and emotion. In *Briefe über die ästhetische Erziehung des Menschen* (1795; *Letters on the Aesthetic Education of Man*), the dramatist and literary theorist Friedrich Schiller suggested that while this might apply to modern human beings, it was not the case in ancient Greece where reason and feeling seemed to have been in harmony. (There is, as suggested earlier, some basis for this claim insofar as the Greek moral consciousness did not make the modern distinction between morality and self-interest.) Schiller's suggestion may have been the spark that led Georg Wilhelm Friedrich Hegel (1770–1831) to develop the first philosophical system that has historical change as its core.

As Hegel presents it, all of history is the progress of mind or spirit along a logically necessary path that leads to freedom. Human beings are manifestations of this universal mind, although at first they do not realize this. Freedom cannot be achieved until human beings do realize it, and so feel at home in the universe. There are echoes of Spinoza in Hegel's idea of mind as something universal and also in his conception of freedom as based on knowledge. What is original, however, is the way in which all of history is presented as leading to the goal of freedom. Thus Hegel accepts Schiller's view that for the ancient Greeks, reason and feeling were in harmony, but he sees this as a naive harmony that could exist only as long as the Greeks did not see themselves as free individuals with a conscience independent of the views of the community. For freedom to develop, it was necessary for this harmony to break down. This occurred as a result of the Reformation, with its insistence on the right of individual conscience. But the rise of individual conscience left human beings divided between conscience and self-interest, between reason and feeling. We have seen how many philosophers tried unsuccessfully to bridge this gulf until Kant's insistence that we must do our duty for duty's sake made the division an apparently inevitable part of moral life. For Hegel, however, it can be overcome by a synthesis of the harmonious communal nature of Greek life with the modern freedom of individual conscience.

In *Naturrecht und Staatswissenschaft im Grundrisse*, alternatively entitled *Grundlinien der Philosophie des Rechts* (1821; *The Philosophy of Right*), Hegel described how this synthesis could be achieved in an organic community. The key to his solution is the recognition that human nature is not fixed but is shaped by the society in which one lives. The organic community would foster those desires that most benefit the community. It would imbue its members with the sense that their own identity consists in being a part of the community, so that they would no more think of going off in pursuit of their own private interests than one's left arm would think of going off without the rest of the body. Nor should it be forgotten that such organic relationships are reciprocal: the organic community will no more disregard the interests of its members than an individual would disregard an injury to his or her arm. Harmony would thus prevail but not the naive harmony of ancient Greece. The citizens of Hegel's organic community do not obey its laws and customs simply because they are there. With the independence of mind characteristic of modern times, they can only give their allegiance to institutions that they recognize as conforming to rational principles. The modern organic state, unlike the ancient Greek city-state, is self-consciously based on rationally selected principles.

The concept of the organic community

Hegel provided a new approach to the ancient problem of reconciling morality and self-interest. Others had accepted the problem as part of the inevitable nature of things and looked for ways around it. Hegel looked at it historically and saw it as a problem only in a certain type of society. Instead of solving the problem as it existed, he looked to the emergence of a new form of society in which it would disappear. In this way Hegel claimed to have overcome one great problem that was insoluble for Kant.

Hegel also believed that he had the solution to the other key weakness in Kant's ethics—namely, the difficulty of giving content to the supreme formal moral principle. In Hegel's organic community, the content of our moral duty would be given to us by our position in society. We would know that our duty was to be a good parent, a good citizen, a good teacher, merchant, or soldier, as the case might be. It is an ethic that has been called "my station and its duties." It might be thought that this is a limited, conservative conception of what we ought to do with our lives, especially when compared with Kant's principle of universal law, which does not base what we ought to do on what our particular station in society happens to be. Hegel would have replied that because the organic community is

based on universally valid principles of reason, it complies with Kant's principle of universal law. Moreover, without the specific content provided by the concrete institutions and practices of a society, that principle would remain an empty formula.

Hegel's philosophy has both a conservative and a radical side. The conservative aspect is reflected in the ethic of "my station and its duties," and even more strongly in the significant resemblance between Hegel's detailed description of the organic society and the actual institutions of the Prussian state in which he lived and taught for the last decade of his life. This resemblance, however, was in no way a necessary implication of Hegel's philosophy as a whole. After Hegel's death, a group of his more radical followers known as the Young Hegelians hailed the manner in which he had demonstrated the need for a new form of society to overcome the separation between self and community but scorned the implication that the state in which they were living could be this solution to all the problems of history. Among this group was a young student named Karl Marx.

Marx. Marx (1818–83) has often been presented by his followers as a scientist rather than a moralist. He did not deal directly with the ethical issues that occupied the philosophers so far discussed. His Materialist conception of history is, rather, an attempt to explain all ideas, whether political, religious, or ethical, as the product of the particular economic stage that society has reached. Thus a feudal society will regard loyalty and obedience to one's lord as the chief virtues. A capitalist economy, on the other hand, requires a mobile labour force and expanding markets, so that freedom, especially the freedom to sell one's labour, is its key ethical conception. Because Marx saw ethics as a mere by-product of the economic basis of society, he frequently took a dismissive stance toward it. Echoing the Sophist Thrasymachus, Marx said that the "ideas of the ruling class are in every epoch the ruling ideas." With his coauthor Friedrich Engels, he was even more scornful in the *Manifest der Kommunistischen Partei* (1848; *The Communist Manifesto*), in which morality, law, and religion are referred to as "so many bourgeois prejudices behind which lurk in ambush just as many bourgeois interests."

A sweeping rejection of ethics, however, is difficult to reconcile with the highly moralistic tone of Marx's condemnation of the miseries the capitalist system inflicts upon the working class and with his obvious commitment to hastening the arrival of the Communist society that will end such iniquities. After Marx died, Engels tried to explain this apparent inconsistency by saying that as long as society was divided into classes, morality would serve the interests of the ruling class. A classless society, on the other hand, would be based on a truly human morality that served the interests of all human beings. This does make Marx's position consistent by setting him up as a critic, not of ethics as such, but rather of the class-based moralities that would prevail until the Communist revolution.

By studying Marx's earlier writings—those produced when he was a Young Hegelian—one obtains a slightly different, though not incompatible, impression of the place of ethics in Marx's thought. There seems no doubt that the young Marx, like Hegel, saw human freedom as the ultimate goal. He also held, as did Hegel, that freedom could only be obtained in a society in which the dichotomy between private interest and the general interest had disappeared. Under the influence of socialist ideas, however, he formed the view that merely knowing what was wrong with the world would not achieve anything. Only the abolition of private property could lead to the transformation of human nature and so bring about the reconciliation of the individual and the community. Theory, Marx concluded, had gone as far as it could; even the theoretical problems of ethics, as illustrated in Kant's division between reason and feeling, would remain insoluble unless one moved from theory to practice. This is what Marx meant in the famous thesis that is engraved on his tombstone: "The philosophers have only interpreted the world, in various ways; the point is to change it." The goal of changing the world stemmed from Marx's attempt to overcome one of the central problems of ethics; the means now passed beyond philosophy.

Nietzsche. Friedrich Nietzsche (1844–1900) was a literary and social critic, not a systematic philosopher. In ethics, the chief target of his criticism is the Judeo-Christian tradition. He describes Jewish ethics as a "slave morality" based on envy. Christian ethics is, in his opinion, even worse because it makes a virtue of meekness, poverty, and humility, telling one to turn the other cheek rather than to struggle. It is the ethics of the weak, who hate and fear strength, pride, and self-affirmation. Such an ethics undermines the human drives that have led to the greatest and most noble human achievements.

Nietzsche thought the era of traditional religion to be over: "God is dead," perhaps his most widely repeated aphorism, was his paradoxical way of putting it. Yet, what was to be put in its place? Nietzsche took from Aristotle the concept of greatness of soul, the unchristian virtue that included nobility and a justified pride in one's achievements. He suggested a reevaluation of values that would lead to a new ideal: the *Übermensch*, a term usually translated as "Superman" and given connotations that suggest that Nietzsche would have regarded Hitler as an ideal type. Nietzsche's praise of "the will to power" is taken as further evidence that he would have approved of Hitler. This interpretation owes much to Nietzsche's racist sister, who after his death compiled a volume of his unpublished writings, arranging them to make it appear that he was a forerunner of Nazi thinking. This is at best a partial truth. Nietzsche was almost as contemptuous of pan-German racism and anti-Semitism as he was of the ethics of Judaism and Christianity. What Nietzsche meant by *Übermensch* was a person who could rise above the limitations of ordinary morality; and by "the will to power" it seems that Nietzsche had in mind self-affirmation and not necessarily the use of power to oppress others.

The concept of the *Übermensch* and its implications

Nevertheless, Nietzsche left himself wide open to those who wanted his philosophical imprimatur for their crimes against humanity. His belief in the importance of the *Übermensch* made him talk of ordinary people as "the herd," who did not really matter. In *Jenseits von Gut und Böse* (1886; *Beyond Good and Evil*), he wrote with approval of "the distinguished type of morality," according to which "one has duties only toward one's equals; toward beings of a lower rank, toward everything foreign to one, one may act as one sees fit, 'as one's heart dictates' "—in any event, beyond good and evil. The point is that the *Übermensch* is above all ordinary moral standards: "The distinguished type of human being feels *himself* as value-determining; he does not need to be ratified; he judges 'that which is harmful to me is harmful as such'; he knows that *he* is the something which gives value to objects; he *creates values*." In this Nietzsche was a forerunner of Existentialism rather than Nazism, but then Existentialism, precisely because it gives no basis for choosing other than authenticity, is not incompatible with Nazism.

Nietzsche's position on ethical matters represents a stark contrast to that of Henry Sidgwick, the last major figure of 19th-century British ethics treated in this article. Sidgwick believed in objective standards for ethical judgments and thought that the subject of ethics had over the centuries made progress toward these standards. He saw his own work as building carefully on that progress. Nietzsche, on the other hand, would have us sweep away everything since Greek ethics and not keep much of that either. The superior types would then be able to freely create their own values as they saw fit.

20th-century Western ethics

The brief historical survey of Western ethics from Socrates to the 20th century provided above has shown three constant themes. Since the Sophists, there have been (1) disagreements over whether ethical judgments are truths about the world or only reflections of the wishes of those who make them; (2) frequent attempts to show, in the face of considerable skepticism, either that it is in one's own interests to do what is good or that, even though this is not necessarily in one's own interests, it is the ratio-

nal thing to do; and (3) repeated debates over just what goodness and the standard of right and wrong might be. The 20th century has seen new twists to these old themes and an increased attention to the application of ethics to practical problems. Each of these major questions is considered below in terms of metaethics, normative ethics, and applied ethics.

METAETHICS

As previously noted, metaethics deals not with substantive ethical theories or moral judgments but rather with questions about the nature of these theories and judgments. Among 20th-century philosophers in English-speaking countries, those defending the objectivity of ethical judgments have most often been intuitionists or naturalists; those taking a different view have been emotivists or prescriptivists.

Moore and the naturalistic fallacy. At first it was the intuitionists who dominated the scene. In 1903 the Cambridge philosopher G.E. Moore presented in *Principia Ethica* his "open question argument" against what he called the naturalistic fallacy. The argument can in fact be found in Sidgwick and to some extent in the 18th-century intuitionists, but Moore's statement of it somehow caught the imagination of philosophers for the first half of the 1900s. Moore's aim was to prove that "good" is the name of a simple, unanalyzable quality. His chief target was the attempt to define good in terms of some natural quality of the world whether it be "pleasure" (he had John Stuart Mill in mind), or "more evolved" (here he refers to Herbert Spencer, who had tried to build an ethical system around Darwin's theory of evolution), or simply the idea of what is natural itself, as in appeals to a law of nature—hence the label naturalistic fallacy (*i.e.,* the fallacy of treating good as if it were the name of a natural property). But the label is not apt because Moore's argument applied, as he acknowledged, to any attempt to define good in terms of something else, including something metaphysical or supernatural such as "what God wills."

The naturalistic fallacy

The so-called open question argument itself is simple enough. It consists of taking the proposed definition of good and turning it into a question. For instance, if the proposed definition is "Good means whatever leads to the greatest happiness of the greatest number," then Moore would ask: "Is whatever leads to the greatest happiness of the greatest number good?" Moore is not concerned whether we answer yes or no. His point is that if the question is at all meaningful—if a negative answer is not plainly self-contradictory—then the definition cannot be right, for a definition is supposed to preserve the meaning of the term defined. If it does, a question of the type Moore asks would be absurd for all who understand the meaning of the term. Compare, for example, "Do all squares have four equal sides?"

Moore's argument does show that definitions of the kind he criticized do not capture all that we ordinarily mean by the term good. It would still be open to a would-be naturalist to admit that the definition does not capture everything that we ordinarily mean by the term, and add that all this shows is that ordinary usage is muddled and in need of revision. (We shall see that J.L. Mackie was later to make this part of his defense of subjectivism.) As for Mill, it is questionable whether he really intended to offer a definition of the term good; he seems to have been more interested in offering a criterion by which we could ascertain which actions are good. As Moore acknowledged, the open question argument does not do anything to show that pleasure, for example, is not the sole criterion of the goodness of an action. It shows only that this cannot be known to be true by definition, and so, if it is to be known at all, it must be known by some other means.

In spite of these doubts, Moore's argument was widely accepted at the time as showing that all attempts to derive ethical conclusions from anything not itself ethical in nature are bound to fail. The point was soon seen to be related to that made by Hume in his remarks on writers who move from "is" to "ought." Moore, however, would have considered Hume's own account of morality to be naturalistic because of its definition of virtue in terms of the sentiments of the spectator. The upshot was that for 30 years after the publication of *Principia Ethica* intuitionism was the dominant metaethical position in British philosophy. In addition to Moore, its supporters included H.A. Prichard and Sir W.D. Ross.

Modern intuitionism. The 20th-century intuitionists were not far removed philosophically from their 18th-century predecessors—those such as Richard Price who had learned from Hume's criticism and did not attempt to reason his way to ethical conclusions but claimed rather that ethical knowledge is gained through an immediate apprehension of its truth. In other words, a true ethical judgment is self-evident as long as we are reflecting clearly and calmly and our judgment is not distorted by self-interest or faulty moral upbringing. Ross, for example, took "the convictions of thoughtful, well-educated people" as "the data of ethics," observing that while some may be illusory, they should only be rejected when they conflict with others that are better able to stand up to "the test of reflection."

The intuitionists differed on the nature of the moral truths that are apprehended in this way. For Moore it was self-evident that certain things are valuable: *e.g.,* the pleasures of friendship and the enjoyment of beauty. On the other hand, Ross thought we know it to be our duty to do acts of a certain type. These differences will be dealt with in the discussion of normative ethics. They are, however, significant to metaethical intuitionism because they reveal the lack of agreement, even among the intuitionists themselves, about moral judgments that each claims to be self-evident.

This disagreement was one of the reasons for the eventual rejection of intuitionism, which, when it came, was as complete as its acceptance had been in earlier decades. But there was also a more powerful philosophical motive working against intuitionism. During the 1930s, Logical Positivism, brought from Vienna by Ludwig Wittgenstein and popularized by A.J. Ayer in his manifesto *Language, Truth and Logic* (1936), became influential in British philosophy. According to the Logical Positivists, all true statements fall into two categories: logical truths and statements of fact. Moral judgments cannot fit comfortably into either category. They cannot be logical truths, for these are mere tautologies that can tell us nothing more than what is already contained in the definitions of the terms. Nor can they be statements of fact because these must, according to the Logical Positivists, be at least in principle verifiable; there is no way of verifying the truths that the intuitionists claimed to apprehend. The truths of mathematics, on which intuitionists had continued to rely as the one clear parallel case of a truth known by its self-evidence, were explained now as logical truths. In this view, mathematics tells us nothing about the world; it is simply a logical system, true by the definitions of the terms involved, which may be useful in our dealings with the world. Thus the intuitionists lost the one useful analogy to which they could appeal in support of the existence of a body of self-evident truths known by reason alone. It seemed to follow that moral judgments could not be truths at all.

Impact of Logical Positivism

Emotivism. In his above-cited *Language, Truth and Logic,* Ayer offered an alternative account: moral judgments are not statements at all. When we say, "You acted wrongly in stealing that money," we are not expressing any fact beyond that stated by "You stole that money." It is, however, as if we had stated this fact with a special tone of abhorrence, for in saying that something is wrong, we are expressing our feelings of disapproval toward it.

This view was more fully developed by Charles Stevenson in *Ethics and Language* (1945). As the titles of books of this period suggest, philosophers were now paying more attention to language and to the different ways in which it could be used. Stevenson distinguished the facts a sentence may convey from the emotive impact it is intended to have. Moral judgments are significant, he urged, because of their emotive impact. In saying that something is wrong, we are not merely expressing our disapproval of it, as Ayer suggested. We are encouraging those to whom we speak to share our attitude. This is why we bother to

argue about our moral views, while on matters of taste we may simply agree to differ. It is important to us that others share our attitudes on war, equality, or killing; we do not care if they prefer to take their tea with lemon and we do not.

Charges of subjectivism

The emotivists were immediately accused of being subjectivists. In one sense of the term subjectivist, the emotivists could firmly reject this charge. Unlike other subjectivists in the past, they did not hold that those who say, for example, "Stealing is wrong," are making a statement of fact about their own feelings or attitudes toward stealing. This view—more properly known as subjective naturalism because it makes the truth of moral judgments depend on a natural, albeit subjective, fact about the world—could be refuted by Moore's open question argument. It makes sense to ask: "I know that I have a feeling of approval toward this, but is it good?" It was the emotivists' view, however, that moral judgments make no statements of fact at all. The emotivists could not be defeated by the open question argument because they agreed that no definition of "good" in terms of facts, natural or unnatural, could capture the emotive element of its meaning. Yet, this reply fails to confront the real misgivings behind the charge of subjectivism: the concern that there are no possible standards of right and wrong other than one's own subjective feelings. In this sense, the emotivists were subjectivists.

Existentialism. About this time a different form of subjectivism was becoming fashionable on the Continent and to some extent in the United States. Existentialism was as much a literary as a philosophical movement. Its leading figure, Jean-Paul Sartre, propounded his ideas in novels and plays as well as in his major philosophical treatise, *L'Être et le néant* (1943; *Being and Nothingness*). For Sartre, because there is no God, human beings have not been designed for any particular purpose. The Existentialists express this by stating that our existence precedes our essence. In saying this, they make clear their rejection of the Aristotelian notion that just as we can recognize a good knife once we know that the essence of a knife is to cut, so we can recognize a good human being once we understand the essence of human nature. Because we have not been designed for any specific end, we are free to choose our own essence, which means to choose how we will live. To say that we are compelled by our situation, our nature, or our role in life to act in a certain way is to exhibit "bad faith." This seems to be the only term of disapproval the Existentialists are prepared to use. As long as we choose "authentically," there are no moral standards by which our conduct can be criticized.

Relativity of all moral standards

This, at least, is the view most widely held by the Existentialists. In one work, a brochure entitled *L'Existentialisme est un humanisme* (1946; "Existentialism Is a Humanism"; Eng. trans., *Existentialism and Humanism*), Sartre backs away from so radical a subjectivism by suggesting a version of Kant's idea that we must be prepared to apply our judgments universally. He does not reconcile this view with conflicting statements elsewhere in his writings, and it is doubtful if it can be regarded as a statement of his true ethical views. It may reflect, however, a widespread postwar reaction to the spreading knowledge of what happened at Auschwitz and other Nazi death camps. One leading German prewar Existentialist, Martin Heidegger, had actually become a Nazi. Was this "authentic choice" just as good as Sartre's own choice to join the French Résistance? Is there really no firm ground from which such a choice could be rejected? This seemed to be the upshot of the pure Existentialist position, just as it was an implication of the ethical emotivism that was dominant among English-speaking philosophers. It is scarcely surprising that many philosophers should search for a metaethical view that did not commit them to this conclusion. The means used by Sartre in *L'Existentialisme est un humanisme* were also to have their parallel, though in a much more sophisticated form, in British moral philosophy.

Universal prescriptivism. In *The Language of Morals* (1952), R.M. Hare supported some of the elements of emotivism but rejected others. He agreed that in making moral judgments we are not primarily seeking to describe anything; but neither, he said, are we simply expressing our attitudes. Instead, he suggested that moral judgments prescribe; that is, they are a form of imperative sentence. Hume's rule about not deriving an "is" from an "ought" can best be explained, according to Hare, in terms of the impossibility of deriving any prescription from a set of descriptive sentences. Even the description "There is an enraged bull bearing down on you" does not necessarily entail the prescription "Run!" because I may have been searching for ways of killing myself in such a way that my children can still benefit from my life insurance. Only I can choose whether the prescription fits what I want. Herein lies moral freedom: because the choice of prescription is individual, no one can tell another what he or she must think right.

Hare's espousal of the view that moral judgments are prescriptions led commentators on his first book to classify him with the emotivists as one who did not believe in the possibility of using reason to arrive at ethical conclusions. That this was a mistake became apparent with the publication of his second book, *Freedom and Reason* (1963). The aim of the book was to show that the moral freedom guaranteed by prescriptivism is, notwithstanding its element of choice, compatible with a substantial amount of reasoning about moral judgments. Such reasoning is possible, Hare wrote, because moral judgments must be "universalizable." This notion owed something to the ancient Golden Rule and even more to Kant's first formulation of the categorical imperative. In Hare's treatment, however, these ideas were refined so as to eliminate their obvious defects. Moreover, for Hare universalizability is not a substantive moral principle but a logical feature of the moral terms. This means that anyone who uses such terms as right and ought is logically committed to universalizability.

Definition of universalizability

To say that a moral judgment must be universalizable means, for Hare, that if I judge a particular action—say, a man's embezzlement of a million dollars from his employer—to be wrong, I must also judge any relevantly similar action to be wrong. Of course, everything will depend on what is allowed to count as a relevant difference. Hare's answer is that all features may count, except those that contain ineliminable uses of words such as I or my, or singular terms such as proper names. In other words, the fact that he embezzled a million dollars in order to be able to take holidays in Tahiti, whereas I embezzled the same sum so as to channel it from my wealthy employer to those starving in Africa, may be a relevant difference; the fact that the man's crime benefitted him, whereas my crime benefitted me, cannot be so.

This notion of universalizability can also be used to test whether a difference that is alleged to be relevant—for instance, skin colour or even the position of a freckle on one's nose—really is relevant. Hare emphasized that the same judgment must be made in all conceivable cases. Thus if a Nazi were to claim that he may kill a person because that person is Jewish, he must be prepared to prescribe that if, somehow, it should turn out that he is himself of Jewish origin, he should also be killed. Nothing turns on the likelihood of such a discovery; the same prescription has to be made in all hypothetically, as well as actually, similar cases. Since only an unusually fanatical Nazi would be prepared to do this, universalizability is a powerful means of reasoning against certain moral judgments, including those made by the Nazis. At the same time, since there could be fanatical Nazis who are prepared to die for the purity of the Aryan race, the argument of *Freedom and Reason* allows that the role played by reason in ethics does have definite limits. Hare's position at this stage, therefore, appeared to be a compromise between the extreme subjectivism of the emotivists and some more objectivist view of ethics. As so often happens with those who try to take the middle ground, Hare was soon to receive criticism from both sides.

Modern naturalism. For a time, Moore's presentation of the naturalistic fallacy halted attempts to define "good" in terms of natural qualities such as happiness. The effect was, however, both local and temporary. In the United States, Ralph Barton Perry was untroubled by Moore's arguments. His *General Theory of Value* (1926) gave an account of value that was objectivist and much less mys-

terious than the intuitionist accounts, which were at that time dominating British philosophy. Perry suggested that there is no such thing as value until a being desires something, and nothing can have intrinsic value considered apart from all desiring beings. A novel, for example, has no value at all unless there is a being who desires to read it or perhaps use it for some other purpose, such as starting a fire on a cold night. Thus Perry is a naturalist, for he defines value in terms of the natural quality of being desired or, as he puts it, being an object of an interest. His naturalism is objectivist, in spite of this dependence of value on desires, because value is defined as any object of any interest. Accordingly, even if I do not desire, say, this encyclopaedia for any purpose at all, I cannot deny that it has some value so long as there is some being who does desire it. Moreover, Perry believed it followed from his theory that the greatest moral value is to be found in whatever leads to the harmonious integration of interests.

In Britain, Moore's impact was for a long time too great for any form of naturalism to be taken seriously. It was only as a response to Hare's intimation that any principle could be a moral principle so long as it satisfied the formal requirement of universalizability that philosophers such as Philippa Foot, Elizabeth Anscombe, and Geoffrey Warnock began to suggest that perhaps a moral principle must also have a particular kind of content—*i.e.*, it must deal, for instance, with some aspect of wants, welfare, or flourishing.

The problem with these suggestions, Hare soon pointed out, is that if we define morality in such a way that moral principles are restricted to those that maximize well-being, then if there is a person who is not interested in maximizing well-being, moral principles, as we have defined them, will have no prescriptive force for that person. This reply elicited two responses—namely, those of Anscombe and Foot.

Anscombe went back to Aristotle, suggesting that we need a theory of human flourishing that will provide an account of what any person must do in order to flourish, and so will lead to a morality that every one of us has reason to follow. No such theory was forthcoming, however, until 1980 when John Finnis offered a theory of basic human goods in his *Natural Law and Natural Rights*. The book was acclaimed by Roman Catholic moral theologians and philosophers, but natural law ethics continues to have few followers outside these circles.

Foot initially attempted to defend a similarly Aristotelian view in which virtue and self-interest are necessarily linked, but she came to the conclusion that this link could not be made. This led her to abandon the assumption that we all have adequate reasons for doing what is right. Like Hume, she suggested that it depends on what we desire and especially on how much we care about others. She observed that morality is a system of hypothetical, not categorical, imperatives.

A much cruder form of naturalism surfaced from a different direction with the publication of Edward O. Wilson's *Sociobiology: The New Synthesis* (1975). Wilson, a biologist rather than a philosopher, claimed that new developments in the application of evolutionary theory to social behaviour would allow ethics to be "removed from the hands of philosophers" and "biologicized." It was not the first time that a scientist, frustrated by the apparent lack of progress in ethics as compared to the sciences, had proposed some way of transforming ethics into a science. In a later book, *On Human Nature* (1978), Wilson suggested that biology justifies specific values (including the survival of the gene pool) and, because man is a mammal rather than a social insect, universal human rights. Other sociobiologists have gone further still, reviving the claims of earlier "social Darwinists" to the effect that Darwin's theory of evolution shows why it is right that there should be social inequality.

Attempt to transform ethics into a science

As the above section on the origin of ethics suggests, evolutionary theory may indeed have something to reveal about the origins and nature of the systems of morality used by human societies. Wilson is, however, plainly guilty of breaching Hume's rule when he tries to draw from a theory of a factual nature ethical premises that tell us what we ought to do. It may be that, coupled with the premise that we wish our species to survive for as long as possible, evolutionary theory will suggest the direction we ought to take, but even that premise cannot be regarded as unquestionable. It is not impossible to imagine circumstances in which life is so grim that extinction is preferable. That choice cannot be dictated by science. It is even less plausible to suppose that more specific choices about social equality can be settled by evolutionary theory. At best, the theory would indicate the costs we might incur by moving to greater equality; it could not conceivably tell us whether incurring those costs is justifiable.

Recent developments in metaethics. In view of the heat of the debate between Hare and his naturalist opponents during the 1960s, the next development was surprising. At first in articles and then in the book *Moral Thinking* (1981), Hare offered a new understanding of what is involved in universalizability that relies on treating moral ideals in a similar fashion to ordinary desires or preferences. In *Freedom and Reason* the universalizability of moral judgments prevented me from giving greater weight to my own interests, simply on the grounds that they are mine, than I was prepared to give to anyone else's interests. In *Moral Thinking* Hare argued that to hold an ideal, whether it be a Nazi ideal such as the purity of the Aryan race or a more conventional ideal such as that justice must be done irrespective of the consequences, is really to have a special kind of preference. When I ask whether I can prescribe a moral judgment universally, I must take into account all the ideals and preferences held by all those who will be affected by the action I am judging; and in taking these into account, I cannot give any special weight to my own ideals merely because they are my own. The effect of this application of universalizability is that for a moral judgment to be universalizable it must ultimately be based on the maximum possible satisfaction of the preferences of all those affected by it. Thus Hare claimed that his reading of the formal property of universalizability inherent in moral language enables him to solve the ancient problem of showing how reason can, at least in principle, resolve ethical disagreement. Moral freedom, on the other hand, has been reduced to the freedom to be an amoralist and to avoid using moral language altogether.

Hare's position was immediately challenged by J.L. Mackie in *Ethics: Inventing Right and Wrong* (1977). In the course of a defense of moral subjectivism, Mackie argued that Hare had stretched the notion of universalizability far beyond anything that is really inherent in moral language. Moreover, even if such a notion were embodied in our way of thinking and talking about morality, Mackie insisted that we would always be free to reject such notions and to decide what to do without concerning ourselves with whether our judgments are universalizable in Hare's, or indeed in any, sense. According to Mackie, our ordinary use of moral language presupposes that moral judgments are statements about something in the universe and, therefore, can be true or false. This is, however, a mistake. Drawing on Hume, Mackie says that there cannot be any matters of fact that make it rational for everyone to act in a certain way. If we do not reject morality altogether, we can only base our moral judgments on our own desires and feelings.

There are a number of contemporary British philosophers who do not accept either Hare's or Mackie's metaethical views. Those who hold forms of naturalism have already been mentioned. Others, including the Oxford philosophers David Wiggins and John McDowell, have employed modern semantic theories of the nature of truth to show that even if moral judgments do not correspond to any objective facts or self-evident truths, they may still be proper candidates for being true or false. This position has become known as moral realism. For some, it makes moral judgments true or false at the cost of taking objectivity out of the notion of truth.

Moral realism

Many modern writers on ethics, including Mackie and Hare, share a view of the nature of practical reason derived from Hume. Our reasons for acting morally, they hold, must depend on our desires because reason in action applies only to the best way of achieving what we desire.

This view of practical reason virtually precludes any general answer to the question "Why should I be moral?" Until very recently, this question had received less attention in the 20th century than in earlier periods. In the early part of the century, such intuitionists as H.A. Prichard had rejected all attempts to offer extraneous reasons for being moral. Those who understood morality would, they said, see that it carried its own internal reasons for being followed. For those who could not see these reasons, the situation was reminiscent of the story of the emperor's new clothes.

The question fared no better with the emotivists. They defined morality so broadly that anything an individual desires can be considered to be moral. Thus there can be no conflict between morality and self-interest, and if anyone asks "Why should I be moral?" the emotivist response would be to say "Because whatever you most approve of doing is, by definition, your morality." Here the question is effectively being rejected as senseless, but this reply does nothing to persuade the questioners to act in a benevolent or socially desirable way. It merely tells them that no matter how antisocial their actions may be, they can still be moral as the emotivists define the term.

For Hare, on the other hand, the question "Why should I be moral?" amounts to asking why I should act only on those judgments that I am prepared to universalize; and the answer he gives is that unless this is what I want to do, it is not always possible to give an adult a reason for doing so. At the same time, Hare does believe that if someone asks why children should be brought up to be morally good, the answer is that they are more likely to be happy if they develop habits of acting morally.

Other philosophers have put the question to one side, saying that it is a matter for psychologists rather than for philosophers. In earlier periods, of course, psychology was considered a branch of philosophy rather than a separate discipline, but in fact psychologists have also had little to say about the connection between morality and self-interest. In *Motivation and Personality* (1954) and other works, Abraham H. Maslow developed a psychological theory reminiscent of Shaftesbury in its optimism about the link between personal happiness and moral values, but Maslow's factual evidence was thin. Victor Emil Frankl, a psychotherapist, has written several popular books defending a position essentially similar to that of Joseph Butler on the attainment of happiness. The gist of this view is known as the paradox of hedonism. In *The Will to Meaning* (1969), Frankl states that those who aim directly at happiness do not find it; those whose lives have meaning or purpose apart from their own happiness find happiness as well.

Psychological theories on the connection between morality and self-interest

The U.S. philosopher Thomas Nagel has taken a different approach to the question of how we may be motivated to act altruistically. Nagel challenges the assumption that Hume was right about reason being subordinate to desires. In *The Possibility of Altruism* (1969), Nagel sought to show that if reason must always be based on desire, even our normal idea of prudence (that we should give the same weight to our future pains and pleasures as we give to our present ones) becomes incoherent. Once we accept the rationality of prudence, however, Nagel argued that a very similar line of argument can lead us to accept the rationality of altruism—*i.e.*, the idea that the pains and pleasures of another individual are just as much a reason for one to act as are one's own pains and pleasures. This means that reason alone is capable of motivating moral action; hence, it is unnecessary to appeal to self-interest or benevolent feelings. Though not an intuitionist in the ordinary sense, Nagel has effectively reopened the 18th-century debate between the moral sense school and the intuitionists who believed that reason alone can play a role in action.

The most influential work in ethics by a U.S. philosopher since the early 1960s, John Rawls's *Theory of Justice* (1971), is for the most part centred on normative ethics, and so will be discussed in the next section; it has, however, had some impact in metaethics as well. To argue for his principles of justice, Rawls uses the idea of a hypothetical contract, in which the contracting parties are behind a "veil of ignorance" that prevent them from knowing any particular details about their own attributes. Thus one cannot try to benefit oneself by choosing principles of justice that favour the wealthy, the intelligent, males, or whites. The effect of this requirement is in many ways similar to Hare's idea of universalizability, but Rawls claims that it avoids, as the former does not, the trap of grouping together the interests of different individuals as if they all belonged to one person. Accordingly, the old social contract model that had largely been neglected since the time of Rousseau has had a new wave of popularity as a form of argument in ethics.

Revival of the notion of social contract

The other aspect of Rawls's thought to have metaethical significance is his so-called method of reflective equilibrium—the idea that a sound moral theory is one that matches reflective moral judgments. In *A Theory of Justice* Rawls uses this method to justify tinkering with the original model of the hypothetical contract until it produces results that are not too much at odds with ordinary ideas of justice. To his critics, this represents a reemergence of a conservative form of intuitionism, for it means that new moral theories are tested against ordinary moral intuitions. If a theory fails to match enough of these, it will be rejected no matter how strong its own foundations may be. In Rawls's defense it may be said that it is only our "reflective moral judgments" that serve as the testing ground—our ordinary moral intuitions may be rejected, perhaps simply because they are contrary to a well-grounded theory. If such be the case, the charge of conservatism may be misplaced, but in the process the notion of some independent standard by which the moral theory may be tested has been weakened, perhaps so far as to become virtually meaningless.

Perhaps the most impressive work of metaethics published in the United States in recent years is R.B. Brandt's *Theory of the Good and the Right* (1979). Brandt returns to something like the naturalism of Ralph Barton Perry but with a distinctive late 20th-century American twist. He spends little time on the concept of good, believing that everything capable of being expressed by this word can be more clearly stated in terms of rational desires. To explicate this notion of a rational desire, Brandt appeals to cognitive psychotherapy. An ideal process of cognitive psychotherapy would eliminate many desires: those based on false beliefs, those which one has only because one is ignoring the feelings or desires that are likely to be expressed in the future, the desires or aversions that are artificially caused by others, desires that are based on early deprivation, and so on. The desires that an individual would still have, undiminished in strength after going through this process, are what Brandt is prepared to call rational desires.

Brandt's notion of rational desire

In contrast to his view of the term good, Brandt does think that the notions of morally right and morally wrong are useful. He suggests that, in calling an action morally wrong, we should mean that it would be prohibited by any moral code that all fully rational people would support for the society in which they are to live. (Brandt then argues that fully rational people would support that moral code which would maximize happiness, but the justification of this claim is a task for normative ethics, not metaethics.)

Brandt's final chapter is an indication of the revival of interest in the question, as he phrases it, "Is it always rational to act morally?" His answer, echoing Shaftesbury in modern guise, is that such desires as benevolence would survive cognitive psychotherapy, and so a rational person would be benevolent. A rational person would also have other moral motives, including an aversion to dishonesty. These motives will occasionally conflict with self-interested desires, and there can be no guarantee that the moral motives will be the stronger. If they are not, and in spite of the fact that a rational person would support a code favouring honesty, Brandt is unable to say that it would be irrational to follow self-interest rather than morality. A fully rational person might support a certain kind of moral code and yet not act in accordance with it on every occasion.

As the century draws to a close, the issues that divided Plato and the Sophists are still dividing moral philoso-

phers. Ironically, the one position that now has few defenders is Plato's view that "good" refers to an idea or property having an objective existence quite apart from anyone's attitudes or desires—on this point the Sophists appear to have won out at last. Yet, this still leaves ample room for disagreement about the extent to which reason can bring about agreed decisions on what we ought to do. There also remains the dispute about whether it is proper to refer to moral judgments as true and false. On the other central question of metaethics, the relationship between morality and self-interest, a complete reconciliation of the two continues to prove—at least for those not prepared to appeal to a belief in reward and punishment in another life—as elusive as it did for Sidgwick at the end of the 19th century.

NORMATIVE ETHICS

The debate over consequentialism. Normative ethics seeks to set norms or standards for conduct. The term is commonly used in reference to the discussion of general theories about what one ought to do, a central part of Western ethics since ancient times. Normative ethics continued to hold the spotlight during the early years of the 20th century, with intuitionists such as W.D. Ross engaged in showing that an ethic based on a number of independent duties was superior to Utilitarianism. With the rise of Logical Positivism and emotivism, however, the logical status of normative ethics seemed doubtful: Was it not simply a matter of whatever one approved? Nor was the analysis of language, which dominated philosophy in English-speaking countries during the 1950s, any more congenial to normative ethics. If philosophy could do no more than analyze words and concepts, how could it offer guidance about what one ought to do? The subject was therefore largely neglected until the 1960s, when emotivism and linguistic analysis were both on the retreat and moral philosophers once again began to think about how individuals ought to live.

A crucial question of normative ethics is whether actions are to be judged right or wrong solely on the basis of their consequences. Traditionally, those theories that judge actions by their consequences have been known as teleological theories, while those that judge actions according to whether they fall under a rule have been referred to as deontological theories. Although the latter term continues to be used, the former has been replaced to a large extent by the more straightforward term consequentialist. The debate over this issue has led to the development of different forms of consequentialist theories and to a number of rival views.

Classical Utilitarianism as the simplest form

Varieties of consequentialism. The simplest form of consequentialism is classical Utilitarianism, which holds that every action is to be judged good or bad according to whether its consequences do more than any alternative action to increase—or, if that is impossible, to limit any unavoidable decrease in—the net balance of pleasure over pain in the universe. This is often called hedonistic Utilitarianism.

G.E. Moore's normative position offers an example of a different form of consequentialism. In the final chapters of the aforementioned *Principia Ethica* and also in *Ethics* (1912), Moore argued that the consequences of actions are decisive for their morality, but he did not accept the classical Utilitarian view that pleasure and pain are the only consequences that matter. Moore asked his readers to picture a world filled with all possible imaginable beauty but devoid of any being who can experience pleasure or pain. Then the reader is to imagine another world, as ugly as can be but equally lacking in any being who experiences pleasure or pain. Would it not be better, Moore asked, that the beautiful world rather than the ugly world exist? He was clear in his own mind that the answer was affirmative, and he took this as evidence that beauty is good in itself, apart from the pleasure it brings. He also considered that the friendship of close personal relationships has a similar intrinsic value independent of its pleasantness. Moore thus judged actions by their consequences but not solely by the amount of pleasure they produced. Such a position was once called ideal Utilitarianism because it was a form of Utilitarianism based on certain ideals. Today, however, it is more frequently referred to by the general label consequentialism, which includes, but is not limited to, Utilitarianism.

R.M. Hare is another example of a consequentialist. His interpretation of universalizability leads him to the view that for a judgment to be universalizable, it must prescribe what is most in accord with the preferences of all those affected by the action. This form of consequentialism is frequently called preference Utilitarianism because it attempts to maximize the satisfaction of preferences, just as classical Utilitarianism endeavours to maximize pleasure or happiness. Part of the attraction of such a view lies in the way in which it avoids making judgments about what is intrinsically good, finding its content instead in the desires that people, or sentient beings generally, do have. Another advantage is that it overcomes the objection, which so deeply troubled Mill, that the production of simple, mindless pleasure becomes the supreme goal of all human activity. Against these advantages we must put the fact that most preference Utilitarians want to base their judgments, not on the desires that people actually have, but rather on those they would have if they were fully informed and thinking clearly. It then becomes essential to discover what people would want under these conditions, and, because most people most of the time are less than fully informed and clear in their thoughts, the task is not an easy one.

Preference Utilitarianism

It may also be noted in passing that Hare claims to derive his version of Utilitarianism from universalizability, which in turn he draws from moral language and moral concepts. Moore, on the other hand, had simply found it self-evident that certain things were intrinsically good. Another Utilitarian, the Australian philosopher J.J.C. Smart, has defended hedonistic Utilitarianism by asserting that he has a favourable attitude to making the surplus of happiness over misery as large as possible. As these differences suggest, consequentialism can be held on the basis of widely differing metaethical views.

Consequentialists may also be separated into those who ask of each individual action whether it will have the best consequences, and those who ask this question only of rules or broad principles and then judge individual actions by whether they fall under a good rule or principle. The distinction having arisen in the specific context of Utilitarian ethics, the former are known as act-Utilitarians and the latter as rule-Utilitarians.

Rule-Utilitarianism developed as a means of making the implications of Utilitarianism less shocking to ordinary moral consciousness. (The germ of this approach is seen in Mill's defense of Utilitarianism.) There might be occasions, for example, when stealing from one's wealthy employer in order to give to the poor would have good consequences. Yet, surely it would be wrong to do so. The rule-Utilitarian solution is to point out that a general rule against stealing is justified on Utilitarian grounds, because otherwise there could be no security of property. Once the general rule has been justified, individual acts of stealing can then be condemned whatever their consequences because they violate a justifiable rule.

This suggests an obvious question, one already raised by the above account of Kant's ethics: How specific may the rule be? Although a rule prohibiting stealing may have better consequences than no rule at all against stealing, would not the best consequences of all follow from a rule that permitted stealing only in those special cases in which it is clear that stealing will have better consequences than not stealing? But what then is the difference between act- and rule-Utilitarianism? In *Forms and Limits of Utilitarianism* (1965), David Lyons argued that if the rule were formulated with sufficient precision to take into account all its causally relevant consequences, rule-Utilitarianism would collapse into act-Utilitarianism. If rule-Utilitarianism is to be maintained as a distinct position, then there must be some restriction on how specific the rule can be so that at least some relevant consequences are not taken into account.

To ignore relevant consequences is to break with the very essence of consequentialism; rule-Utilitarianism is

Rule-Utilitarianism versus act-Utilitarianism

therefore not a true form of Utilitarianism at all. That, at least, is the view taken by Smart, who has derided rule-Utilitarianism as "rule-worship" and consistently defended act-Utilitarianism. Of course, when time and circumstances make it awkward to calculate the precise consequences of an action, Smart's act-Utilitarian will resort to rough and ready "rules of thumb" for guidance; but these rules of thumb have no independent status apart from their usefulness in predicting likely consequences, and if ever we are clear that we will produce better consequences by acting contrary to the rule of thumb, we should do so. If this leads us to do things that are contrary to the rules of conventional morality, then, Smart says, so much the worse for conventional morality.

Today, straightforward rule-Utilitarianism has few supporters. On the other hand, a number of more complex positions have been proposed, bridging in some way the distance between rule-Utilitarianism and act-Utilitarianism.

Intuitive level of moral thought

In *Moral Thinking* Hare distinguished two levels of thought about what we ought to do. At the critical level we may reason about the principles that should govern our action and consider what would be for the best in a variety of hypothetical cases. The correct answer here, Hare believed, is always that the best action will be the one that has the best consequences. This principle of critical thinking is not, however, well-suited for everyday moral decision making. It requires calculations that are difficult to carry out under the most ideal circumstances and virtually impossible to carry out properly when we are hurried or liable to be swayed by our emotions or our interests. Everyday moral decisions are the proper domain of the intuitive level of moral thought. At this intuitive level we do not enter into fine calculations of consequences; instead, we act in accordance with fundamental moral principles that we have learned and accepted as determining, for practical purposes, whether an act is right or wrong. Just what these moral principles should be is a task for critical thinking. They must be the principles that, when applied intuitively by most people, will produce the best consequences overall, and they must also be sufficiently clear and brief to be made part of the moral education of children. Hare therefore can avoid the dilemma of the rule-Utilitarian while still preserving the advantages of that position. Given that ordinary moral beliefs reflect the experience of many generations, Hare believed that judgments made at the intuitive level will probably not be too different from judgments made by conventional morality. At the same time, Hare's restriction on the complexity of the intuitive principles is fully consequentialist in spirit.

Some recently published work has gone further still in this direction. Following on earlier discussions of the difficulties consequentialists may have in trusting one another—since the word of a Utilitarian is only as good as the consequences of keeping the promise appear to him to be—Donald Regan has explored the problems of cooperation among Utilitarians in his *Utilitarianism and Co-operation* (1980) and has come out with a further variation designed to make cooperation feasible and thus to achieve the best consequences on the whole. In *Reasons and Persons* (1984), Derek Parfit argued that to aim always at producing the best consequences would be indirectly self-defeating; we would be cutting ourselves off from some of the greatest goods of human life, including those close personal relationships that demand that we sacrifice the ideal of impartial benevolence to all in order that we may give preference to those we love. We therefore need, Parfit suggested, not simply a theory of what we should all do, but a theory of what motives we should all have. Parfit, like Hare, plausibly contended that recognizing this distinction will bring the practical application of consequentialist theories closer to conventional moral judgments.

An ethic of prima facie duties. In the first third of the 20th century, it was the intuitionists, especially W.D. Ross, who provided the major alternative to Utilitarianism. Because of this situation, the position described below is sometimes called intuitionism, but it seems less likely to cause confusion if we reserve that label for the quite distinct metaethical position held by Ross—and incidentally by Sidgwick as well—and refer to the normative position by the more descriptive label, an "ethic of prima facie duties."

Ross's normative ethic consists of a list of duties, each of which is to be given independent weight: fidelity, reparation, gratitude, beneficence, nonmaleficence, and self-improvement. If an act falls under one and only one of these duties, it ought to be carried out. Often, of course, an act will fall under two or more duties: I may owe a debt of gratitude to someone who once helped me, but beneficence will be better served if I help others in greater need. This is why the duties are, Ross says, prima facie rather than absolute; each duty can be overridden if it conflicts with a more stringent duty.

An ethic structured in this manner may match our ordinary moral judgments more closely than a consequentialist ethic, but it suffers from two serious drawbacks. First, how can we be sure that just those duties listed by Ross are independent sources of moral obligation? Ross could only respond that if we examine them closely we will find that these, and these alone, are self-evident. But others, even other intuitionists, have found that what was self-evident to Ross was not self-evident to them. Second, if we grant Ross his list of independent prima facie moral duties, we still need to know how to decide, in a particular situation, when a less stringent duty is overridden by a more stringent one. Here, too, Ross had no better answer than an unsatisfactory appeal to intuition.

Rawls's theory as an alternative to Utilitarianism

Rawls's theory of justice. When philosophers again began to take an interest in normative ethics in the 1960s after an interval of some 30 years, no theory could rival the ability of Utilitarianism to provide a plausible and systematic basis for moral judgments in all circumstances. Yet, many people found themselves unable to accept Utilitarianism. One common ground for dissatisfaction was that Utilitarianism does not offer any principle of justice beyond the basic idea that everyone's happiness—or preferences, depending on the form of Utilitarianism—counts equally. Such a principle is quite compatible with sacrificing the welfare of some to the greater welfare of others. This situation explains the enthusiastic welcome accorded to Rawls's *Theory of Justice* when it appeared in 1971. Rawls offered an alternative to Utilitarianism that came close to matching its rival's ability to provide a systematic theory of what one ought to do and, at the same time, led to conclusions about justice very different from those of the Utilitarians.

The "maximin" principle

Rawls asserted that if people had to choose principles of justice from behind a "veil of ignorance" that restricted what they could know of their own position in society, they would not seek to maximize overall utility. Instead, they would safeguard themselves against the worst possible outcome, first, by insisting on the maximum amount of liberty compatible with the like liberty for others; and, second, by requiring that wealth be distributed so as to make the worst-off members of the society as well-off as possible. This second principle is known as the "maximin" principle, because it seeks to maximize the welfare of those at the minimum level of society. Such a principle might be thought to lead directly to an insistence on the equal distribution of wealth, but Rawls points out that if we accept certain assumptions about the effect of incentives and the benefits that may flow to all from the productive labours of the most talented members of society, the maximin principle could allow considerable inequality.

In the decade following its appearance, *A Theory of Justice* was subjected to unprecedented scrutiny by moral philosophers throughout the world. Two major issues emerged: Were the two principles of justice soundly derived from the original contract situation? And did the two principles amount, in themselves, to an acceptable theory of justice?

To the first question, the general verdict was negative. Without appealing to specific psychological assumptions about an aversion to risk—and Rawls disclaimed any such assumptions—there was no convincing way in which Rawls could exclude the possibility that the parties to the original contract would choose to maximize average

utility, thus giving themselves the best possible chance of having a high level of welfare. True, each individual making such a choice would have to accept the possibility that he would end up with a very low level of welfare, but that might be a risk worth running for the sake of a chance at a very high level.

Even if the two principles cannot validly be derived from the original contract, they might be sufficiently attractive to stand on their own either as self-evident moral truths—if we are objectivists—or as principles to which we might have favourable attitudes. Maximin, in particular, has proved attractive in a variety of disciplines, including welfare economics, a field in which preference Utilitarianism once reigned unchallenged. But maximin has also had its critics, who have pointed out that the principle could require us to forgo very great benefits to the vast majority if, for some reason, this would require some loss (no matter how trivial) to the worst-off members of society.

Rights theories. One of Rawls's severest critics, Robert Nozick of the United States, rejected the assumption that lies behind not only the maximin principle but behind any principle that seeks to achieve a pattern of distribution by taking from one group in order to give to another. In attempting to bring about a certain pattern of distribution, Nozick said, these principles ignore the question of how the individuals from whom wealth will be taken acquired their wealth in the first place. If they have done so by wholly legitimate means without violating the rights of others, then Nozick held that no one, not even the state, can have the right to take their wealth from them without their consent.

Although appeals to rights have been common since the great 18th-century declarations of the rights of man, most ethical theorists have treated rights as something that must be derived from more basic ethical principles or else from accepted social and legal practices. Recently, however, there have been attempts to turn this tendency around and make rights the basis of the ethical theory. It is in the United States, no doubt because of its history and constitution, that the appeal to rights as a fundamental moral principle has been most common. Nozick's *Anarchy, State and Utopia* (1974) is one example of a rights-based theory, although it is mostly concerned with the application of the theory in the political sphere and says very little about other areas of normative ethics. Unlike Rawls, who for all his disagreement with Utilitarianism is still a consequentialist of sorts, Nozick is a deontologist. Our rights to life, liberty, and legitimately acquired property are absolute, and no act can be justified if it violates them. On the other hand, we have no duty to assist people in the preservation of their rights. If others go about their own affairs without infringing on the rights of others, I must not infringe on their rights; but if they are starving, I have no duty to share my food with them. We can appeal to the generosity of the rich, but we have absolutely no right to tax them against their will so as to provide relief for the poor. This doctrine has found favour with some Americans on the political right, but it has proved too harsh for most students of ethics.

Rights as the basis of ethical theory

To illustrate the variety of possible theories based on rights, we can take as another example the one propounded by Ronald Dworkin in *Taking Rights Seriously* (1977). Dworkin agreed with Nozick that rights are not to be overridden for the sake of improved welfare; rights are, he said, "trumps" over ordinary consequentialist considerations. Dworkin's view of rights, however, derives from a fundamental right to equal concern and respect. This makes it much broader than Nozick's theory, since respect for others may require us to assist them and not merely leave them to fend for themselves. Accordingly, Dworkin's view obliges the state to intervene in many areas to ensure that rights are respected.

In its emphasis on equal concern and respect, Dworkin's theory is part of a recent revival of interest in Kant's principle of respect for persons as the fundamental principle of ethics. This principle, like the principle of justice, is often said to be ignored by Utilitarians. Rawls invoked it when setting out the underlying rationale of his theory of justice. The concept, however, suffers from vagueness, and attempts to develop it into something more specific that could serve as the basis for a complete ethical theory have not—unless Rawls's theory is to count as one of them—offered a satisfactory basis for ethical decision making.

Natural law ethics. As far as secular moral philosophy is concerned, during most of the 20th century, natural law ethics has been considered a lifeless medieval relic, preserved only in Roman Catholic schools of moral theology. It is still true that the chief proponents of natural law are of that particular religious persuasion, but they have recently begun to defend their position by arguments that make no explicit appeal to their religious beliefs. Instead, they start their ethics with the claim that there are certain basic human goods that we should not act against. In the list offered by John Finnis in *Natural Law and Natural Rights* (1980), for example, these goods are life, knowledge, play, aesthetic experience, friendship, practical reasonableness, and religion. The identification of these goods is a matter of reflection, assisted by the findings of anthropologists. Each of the basic goods is regarded as equally fundamental; there is no hierarchy among them.

It would, of course, be possible to hold a consequentialist ethic that identified several basic human goods of equal importance and judged actions by their tendency to produce or maintain these goods. Thus, if life is a good, any action that led to a preventable loss of life would, other things being equal, be wrong. Natural law ethics, however, rejects this consequentialist approach. It makes the claim that it is impossible to measure the basic goods against each other. Instead of engaging in consequentialist calculations, the natural law ethic is built on the absolute prohibition of any action that aims directly against any basic good. The killing of the innocent, for instance, is always wrong, even if somehow killing one innocent person were to be the only way of saving thousands of innocent people. What is not adequately explained in this rejection of consequentialism is why the life of one innocent person—about whom, let us say, we know no more than that he is innocent—cannot be measured against the lives of a thousand innocent people about whom we have precisely the same information.

The basis of modern natural law ethic

Natural law ethics does allow one means of softening the effect of its absolute prohibitions. This is the doctrine of double effect, traditionally applied by Roman Catholic writers to some cases of abortion. If a pregnant woman is found to have a cancerous uterus, the doctrine of double effect allows a doctor to remove the uterus notwithstanding the fact that such action will kill the fetus. This allowance is made not because the life of the mother is regarded as more valuable than the life of the fetus, but because in removing the uterus the doctor is held not to aim directly at the death of the fetus. Instead, its death is an unwanted and indirect side effect of the laudable act of removing a diseased organ. On the other hand, a different medical condition might mean that the only way of saving the mother's life is by directly killing the fetus. Some years ago before the development of modern obstetric techniques, this was the case if the head of the fetus became lodged during delivery. Then the only way of saving the life of the woman was to crush the skull of the fetus. Such a procedure was prohibited, for in performing it the doctor would be directly killing the fetus. This ruling was applied even to those cases in which the death of the mother would certainly bring about the death of the fetus as well. The claim was that the doctor who killed the fetus directly was responsible for a murder, but the deaths from natural causes of the mother and fetus were not considered to be the doctor's doing. The example is significant because it indicates the lengths to which proponents of the natural law ethics are prepared to go in order to preserve the absolute nature of the prohibitions.

Ethical egoism. All of the normative theories considered so far have had a universal focus—*i.e.*, if they have been consequentialist theories, the goods they sought to achieve were sought for all capable of benefitting from them: and if they were deontological theories, the deontological principles applied equally to whoever might do the act in question. Ethical egoism departs from this consensus, suggesting that we should each consider only

Avoidance of conflict between morality and self-interest

the consequences of our actions for our own interests. The great advantage of such a position is that it avoids any possible conflict between morality and self-interest. If it is rational for us to pursue our own interest, then, if the ethical egoist is right, the rationality of morality is equally clear.

We can distinguish two forms of egoism. The individual egoist says, "Everyone should do what is in my interests." This indeed is egoism, but it is incapable of being couched in a universalizable form, and so it is arguably not a form of ethical egoism. Nor is the individual egoist likely to be able to persuade others to follow a course of action that is so obviously designed to benefit only the person who is advocating it.

Universal egoism is based on the principle "Everyone should do what is in her or his own interests." This principle is universalizable, since it contains no reference to any particular individual and it is clearly an ethical principle. Others may be disposed to accept it because it appears to offer them the surest possible way of furthering their own interests. Accordingly, this form of egoism is from time to time seized upon by some popular writer who proclaims it the obvious answer to all our ills and has no difficulty finding agreement from a segment of the general public. The U.S. writer Ayn Rand is perhaps the best 20th-century example. Rand's version of egoism is expounded in the novel *Atlas Shrugged* (1957) by her hero, John Galt, and in *The Virtue of Selfishness* (1965), a collection of her essays. It is a confusing mixture of appeals to self-interest and suggestions that everyone will benefit from the liberation of the creative energy that will flow from unfettered self-interest. Overlaying all this is the idea that true self-interest cannot be served by stealing, cheating, or similarly antisocial conduct.

As this example illustrates, what starts out as a defense of ethical egoism very often turns into an indirect form of Utilitarianism; the claim is that we will all be better off if each of us does what is in his or her own interest. The ethical egoist is virtually compelled to make this claim because otherwise there is a paradox in the fact that the ethical egoist advocates ethical egoism at all. Such advocacy would be contrary to the very principle of ethical egoism, unless the egoist benefits from others' becoming ethical egoists. If we see our interests as threatened by others' pursuing their own interests, we will certainly not benefit by others' becoming egoists; we would do better to keep our own belief in egoism secret and advocate altruism.

Unfortunately for ethical egoism, the claim that we will all be better off if every one of us does what is in his or her own interest is incorrect. This is shown by what are known as "prisoner's dilemma" situations, which are playing an increasingly important role in discussions of ethical theory. The basic prisoner's dilemma is an imaginary situation in which two prisoners are accused of a crime. If one confesses and the other does not, the prisoner who confesses will be released immediately and the other who does not will spend the next 20 years in prison. If neither confesses, each will be held for a few months and then both will be released. And if both confess, they will each be jailed for 15 years. The prisoners cannot communicate with one another. If each of them does a purely self-interested calculation, the result will be that it is better to confess than not to confess no matter what the other prisoner does. Paradoxical as it might seem, two prisoners, each pursuing his own interest, will end up worse than they would if they were not egoists.

The example might seem bizarre, but analogous situations occur quite frequently on a larger scale. Consider the dilemma of the commuter. Suppose that each commuter finds his or her private car a little more convenient than the bus; but when each of them drives a car, the traffic becomes so congested that everyone would be better off if they all took the bus and the buses moved quickly without traffic holdups. Because private cars are somewhat more convenient than buses, however, and the overall volume of traffic is not appreciably affected by one more car on the road, it is in the interest of each to continue using a private car. At least on the collective level, therefore, egoism is self-defeating—a conclusion well brought out by Parfit in his aforementioned *Reasons and Persons*.

APPLIED ETHICS

The most striking development in the study of ethics since the mid-1960s has been the growth of interest among philosophers in practical, or applied, ethics; *i.e.*, the application of normative theories to practical moral problems. This is not, admittedly, a totally new departure. From Plato onward moral philosophers have concerned themselves with practical questions, including suicide, the exposure of infants, the treatment of women, and the proper behaviour of public officials. Christian philosophers, notably Augustine and Aquinas, examined with great care such matters as when a war was just, whether it could ever be right to tell a lie, or if a Christian woman did wrong to commit suicide in order to save herself from rape. Hobbes had an eminently practical purpose in writing his *Leviathan*, and Hume wrote about the ethics of suicide. Practical concerns continued with the British Utilitarians, who saw reform as the aim of their philosophy: Bentham wrote on an incredible variety of topics, and Mill is celebrated for his essays on liberty and on the subjection of women.

The application of normative theories to practical moral problems

Nevertheless, during the first six decades of the 20th century moral philosophers largely isolated themselves from practical ethics—something that now seems all but incredible, considering the traumatic events through which most of them lived. There were one or two notable exceptions. The philosopher Bertrand Russell was very much involved in practical issues, but his stature among his colleagues was based on his work in logic and metaphysics and had nothing to do with his writings on topics such as disarmament and sexual morality. Russell himself seems to have regarded his practical contributions as largely separate from his philosophical work and did not develop his ethical views in any systematic or rigorous fashion.

The prevailing view of the period was that moral philosophy is quite separate from "moralizing," a task best left to preachers. What was not generally considered was whether moral philosophers could, without merely preaching, make an effective contribution to discussions of practical issues involving difficult ethical questions. The value of such work began to be widely recognized only during the 1960s, when first the U.S. civil rights movement and subsequently the Vietnam War and the rise of student activism started to draw philosophers into discussions of the moral issues of equality, justice, war, and civil disobedience. (Interestingly, there has been very little discussion of sexual morality—an indication that a subject once almost synonymous with the term morals has become marginal to our moral concerns.)

The founding, in 1971, of *Philosophy and Public Affairs*, a new journal devoted to the application of philosophy to public issues, provided both a forum and a new standard of rigour for these contributions. Applied ethics soon became part of the teaching of most philosophy departments of universities in English-speaking countries. Here it is not possible to do more than briefly mention some of the major areas of applied ethics and point to the issues that they raise.

Applications of equality. Since much of the early impetus for applied ethics came from the U.S. civil rights movement, such topics as equality, human rights, and justice have been prominent. We often make statements such as "All humans are equal" without thinking too deeply about the justification for the claims. Since the mid-1960s much has been written about how they can be justified. Discussions of this sort have led in several directions, often following social and political movements. The initial focus, especially in the United States, was on racial equality, and here, for once, there was a general consensus among philosophers on the unacceptability of discrimination against blacks. With so little disagreement about racial discrimination itself, the centre of attention soon moved to reverse discrimination: Is it acceptable to favour blacks for jobs and enrollment in universities and colleges because they had been discriminated against in the past and were generally so much worse off than

Questions related to racial discrimination

whites? Or is this, too, a form of racial discrimination and unacceptable for that reason?

Inequality between the sexes has been another focus of discussion. Does equality here mean ending as far as possible all differences in the sex roles, or could we have equal status for different roles? There has been a lively debate—both between feminists and their opponents and, on a different level, among feminists themselves—about what a society without sexual inequality would be like. Here, too, the legitimacy of reverse discrimination has been a contentious issue. Feminist philosophers have also been involved in debates over abortion and new methods of reproduction. These topics will be covered separately below.

Many discussions of justice and equality are limited in scope to a single society. Even Rawls's theory of justice, for example, has nothing to say about the distribution of wealth between societies, a subject that could make acceptance of his maximin principle much more onerous. But philosophers have now begun to think about the moral implications of the inequality in wealth between the affluent nations (and their citizens) and those living in countries subject to famine. What are the obligations of those who have plenty when others are starving? It has not proved difficult to make a strong case for the view that affluent nations, as well as affluent individuals, ought to be doing much more to help the poor than they are generally now doing.

There is one issue related to equality in which philosophers have led, rather than followed, a social movement. In the early 1970s, a group of young Oxford-based philosophers began to question the assumption that while all humans are entitled to equal moral status, nonhuman animals automatically have an inferior position. The publication in 1972 of *Animals, Men and Morals: An Inquiry into the Maltreatment of Non-humans,* edited by Roslind and Stanley Godlovitch and John Harris, was followed three years later by Peter Singer's *Animal Liberation* and then by a flood of articles and books that established the issue as a part of applied ethics. At the same time, these writings provided the philosophical basis for the animal liberation movement, which has had an effect on attitudes and practices toward animals in many countries.

Environmental ethics. Environmental issues raise a host of difficult ethical questions, including the ancient one of the nature of intrinsic value. Whereas many philosophers in the past have agreed that human experiences have intrinsic value and the Utilitarians at least have always accepted that the pleasures and pains of nonhuman animals are of some intrinsic significance, this does not show why it is so bad if dodos become extinct or a rain forest is cut down. Are these things to be regretted only because of the loss to humans or other sentient creatures? Or is there more to it than that? Some philosophers are now prepared to defend the view that trees, rivers, species (considered apart from the individual animals of which they consist), and perhaps ecological systems as a whole have a value independent of the instrumental value they may have for humans or other sentient creatures.

Issue of obligations to future generations

Our concern for the environment also raises the question of our obligations to future generations. How much do we owe to the future? From a social contract view of ethics or for the ethical egoist, the answer would seem to be: nothing. For we can benefit them, but they are unable to reciprocate. Most other ethical theories, however, do give weight to the interests of coming generations. Utilitarians, for one, would not think that the fact that members of future generations do not exist yet is any reason for giving less consideration to their interests than we give to our own, provided only that we are certain that they will exist and will have interests that will be affected by what we do. In the case of, say, the storage of radioactive wastes, it seems clear that what we do will indeed affect the interests of generations to come.

The question becomes much more complex, however, when we consider that we can affect the size of future generations by the population policies we choose and the extent to which we encourage large or small families. Most environmentalists believe that the world is already dangerously overcrowded. This may well be so, but the notion of overpopulation conceals a philosophical issue that is ingeniously explored by Derek Parfit in *Reasons and Persons* (1984). What is optimum population? Is it that population size at which the average level of welfare will be as high as possible? Or is it the size at which the total amount of welfare—the average multiplied by the number of people—is as great as possible? Both answers lead to counterintuitive outcomes, and the question remains one of the most baffling mysteries in applied ethics.

War and peace. The Vietnam War ensured that discussions as to the justness of a war and of the legitimacy of conscription and civil disobedience were prominent in early writings in applied ethics. There was considerable support for civil disobedience against unjust aggression and against unjust laws even in a democracy.

With the cessation of hostilities in Vietnam and the end of conscription, interest in these questions declined. Concern about nuclear weapons in the early 1980s, however, has caused philosophers to argue about whether nuclear deterrence can be an ethically acceptable strategy if it means using civilian populations as potential nuclear targets. Jonathan Schell's *Fate of the Earth* (1982) raised several philosophical questions about what we ought to do in the face of the possible destruction of all life on our planet.

Abortion, euthanasia, and the value of human life. A number of ethical questions cluster around both ends of the human life span. Whether abortion is morally justifiable has popularly been seen as depending on our answer to the question "When does a human life begin?" Many philosophers believe this to be the wrong question to ask because it suggests that there might be a factual answer that we can somehow discover through advances in science. Instead, these philosophers think we need to ask what it is that makes killing a human being wrong and then consider whether these characteristics, whatever they might be, apply to the fetus in an abortion. There is no generally agreed upon answer, yet some philosophers have presented surprisingly strong arguments to the effect that not only the fetus but even the newborn infant has no right to life. This position has been defended by Jonathan Glover in *Causing Death and Saving Lives* (1977) and in more detail by Michael Tooley in *Abortion and Infanticide* (1984).

Such views have been hotly contested, especially by those who claim that all human life, irrespective of its characteristics, must be regarded as sacrosanct. The task for those who defend the sanctity of human life is to explain why human life, no matter what its characteristics, is specially worthy of protection. Explanation could no doubt be provided in terms of such traditional Christian doctrines as that all humans are made in the image of God or that all humans have an immortal soul. In the current debate, however, the opponents of abortion have eschewed religious arguments of this kind without finding a convincing secular alternative.

Somewhat similar issues are raised by euthanasia when it is nonvoluntary, as, for example, in the case of severely disabled newborn infants. Euthanasia, however, can be voluntary, and this has brought it support from some who hold that the state should not interfere with the free, informed choices of its citizens in matters that do not cause others harm. (The same argument is often invoked in defense of the pro-choice position in the abortion controversy; but it is on much weaker ground in this case because it presupposes what it needs to prove—namely, that the fetus does not count as an "other.") Opposition to voluntary euthanasia has centred on practical matters such as the difficulty of adequate safeguards and on the argument that it would lead to a "slippery slope" that would take us to nonvoluntary euthanasia and eventually to the compulsory involuntary killing of those the state considers to be socially undesirable.

Distinction between killing and allowing to die

Philosophers have also canvassed the moral significance of the distinction between killing and allowing to die, which is reflected in the fact that many physicians will allow a patient with an incurable condition to die when life could still be prolonged, but they will not take active steps to end the patient's life. Consequentialist philosophers, among them both Glover and Tooley, have denied that

this distinction possesses any intrinsic moral significance. For those who uphold a system of absolute rules, on the other hand, a distinction between acts and omissions is essential if they are to render plausible the claim that we must never breach a valid moral rule.

Bioethics. The issues of abortion and euthanasia are included in one of the fastest growing areas of applied ethics, that dealing with ethical issues raised by new developments in medicine and the biological sciences. This subject, known as bioethics, often involves interdisciplinary work, with physicians, lawyers, scientists, and theologians all taking part. Centres for research in bioethics have been established in Australia, Britain, Canada, and the United States. Many medical schools have added the discussion of ethical issues in medicine to their curricula. Governments have sought to deal with the most controversial issues by appointing special committees to provide ethical advice.

Major issues of bioethics

Several key themes run through the subjects covered by bioethics. One, related to abortion and euthanasia, is whether the quality of a human life can be a reason for ending it or for deciding not to take steps to prolong it. Since medical science can now keep alive severely disabled infants who a few years ago would have died soon after birth, pediatricians are regularly faced with this question. The issue received national publicity in Britain in 1981 when a respected pediatrician was charged with murder, following the death of an infant with Down's syndrome. Evidence at the trial indicated that the parents had not wanted the child to live and that the pediatrician had consequently prescribed a narcotic painkiller. The doctor was acquitted. The following year, in the United States, an even greater furor was caused by a doctor's decision to follow the wishes of the parents of a Down's syndrome infant and not carry out surgery without which the baby would die. The doctor's decision was upheld by the Supreme Court of Indiana, and the baby died before an appeal could be made to the U.S. Supreme Court. In spite of the controversy and efforts by government officials to ensure that handicapped infants are given all necessary lifesaving treatment, in neither Britain nor the United States is there any consensus about the decisions that should be made when severely disabled infants are born or by whom these decisions should be made.

Medical advances have raised other related questions. Even those who defend the doctrine of the sanctity of all human life do not believe that doctors have to use extraordinary means to prolong life, but the distinction between ordinary and extraordinary means, like that between acts and omissions, is itself under attack. Critics assert that the wishes of the patient or, if these cannot be ascertained, the quality of the patient's life provides a more relevant basis for a decision than the nature of the means to be used.

Another central theme is that of patient autonomy. This arises not only in the case of voluntary euthanasia but also in the area of human experimentation, which has come under close scrutiny following reported abuses. It is generally agreed that patients must give informed consent to any experimental procedures. But how much and how detailed information is the patient to be given? The problem is particularly acute in the case of randomly controlled trials, which scientists consider the most desirable way of testing the efficacy of a new procedure but which require that the patient agree to being administered randomly one of two or more forms of treatment.

The allocation of medical resources became a life-and-death issue when hospitals obtained dialysis machines and had to choose which of their patients suffering from kidney disease would be able to use the scarce machines. Some argued for "first come, first served," whereas others thought it obvious that younger patients or patients with dependents should have preference. Kidney machines are no longer as scarce, but the availability of various other exotic, expensive lifesaving techniques is limited; hence, the search for rational principles of distribution continues.

New issues arise as further advances are made in biology and medicine. In 1978 the birth of the first human being to be conceived outside the human body initiated a debate about the ethics of in vitro fertilization. This soon led to questions about the freezing of human embryos and what should be done with them if, as happened in 1984 with two embryos frozen by an Australian medical team, the parents should die. The next controversy in this area arose over commercial agencies offering infertile married couples a surrogate mother who would for a fee be impregnated with the sperm of the husband and then surrender the resulting baby to the couple. Several questions emerged: Should we allow women to rent their wombs to the highest bidder? If a woman who has agreed to act as a surrogate changes her mind and decides to keep the baby, should she be allowed to do so?

The culmination of such advances in human reproduction will be the mastery of genetic engineering. Then we will all face the question posed by the title of Jonathan Glover's probing book *What Sort of People Should There Be?* (1984). Perhaps this will be the most challenging issue for 21st-century ethics.

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Applied ethics: Many of the best examples of applied ethics are to be found in journal articles, particularly in *Philosophy and Public Affairs* (quarterly). There are many anthologies of representative samples of such writings. Among the better ones are JAMES RACHELS (ed.), *Moral Problems*, 3rd ed. (1979); JAN NARVESON (ed.), *Moral Issues* (1983); and MANUEL VELASQUEZ and CYNTHIA ROSTANKOWSKI, *Ethics, Theory and Practice* (1985). There are also books and collections on specific topics. MARSHALL COHEN, THOMAS NAGEL, and THOMAS SCANLON (eds.), *Equality and Preferential Treatment* (1977), is a collection of some of the best articles on equality and reverse discrimination; while ALAN H. GOLDMAN, *Justice and Reverse Discrimination* (1979), is a book-length treatment of the issues. Some of the more philosophically probing discussions of feminism are JANET RADCLIFFE RICHARDS, *The Sceptical Feminist* (1980, reprinted with corrections, 1982); MARY MIDGLEY and JUDITH HUGHES, *Women's Choices: Philosophical Problems Facing Feminism* (1983); and ALISON M. JAGGAR, *Feminist Politics and Human Nature* (1983). The moral obligations of the wealthy toward the starving are discussed in the anthology *World Hunger and Moral Obligation*, ed. by WILLIAM AIKEN and HUGH LAFOLLETTE.

The ethics of the treatment of animals has given rise to much philosophical discussion. Books arguing for radical change include STANLEY GODLOVITCH, ROSLIND GODLOVITCH, and JOHN HARRIS (eds.), *Animals, Man, and Morals: An Enquiry into the Maltreatment of Non-Humans* (1971); PETER SINGER, *Animal Liberation: A New Ethics for Our Treatment of Animals* (1975); STEPHEN R.L. CLARK, *The Moral Status of Animals* (1977, reis-

sued 1984); and TOM REGAN, *The Case for Animal Rights* (1983). R.G. FREY, *Interests and Rights: The Case Against Animals* (1980), and *Rights, Killing, and Suffering: Moral Vegetarianism and Applied Ethics* (1983), resist some of these arguments. MARY MIDGLEY, *Animals and Why They Matter* (1983), takes a middle course.

Essays dealing with ethical issues raised by concern for the environment are collected in ROBERT ELLIOT and ARAN GARE (eds.), *Environmental Philosophy* (1983); and K.S. SHRADER-FRECHETTE, *Environmental Ethics* (1981). Useful full-length studies include JOHN PASSMORE, *Man's Responsibility for Nature: Ecological Problems and Western Tradition*, 2nd ed. (1980); and H.J. MCCLOSKEY, *Ecological Ethics and Politics* (1983). For specific problems of future generations, see R. SIKORA and BRIAN BARRY (eds.), *Obligations to Future Generations* (1979). A difficult but fascinating discussion of the problem of optimum population size in an ideal world can be found in DEREK PARFIT, *op. cit.*

MICHAEL WALZER, *Just and Unjust Wars* (1977), is a fine study of the morality of war; RICHARD A. WASSERSTROM (ed.), *War and Morality* (1970), is a valuable collection of essays. NIGEL BLAKE and KAY POLE (eds.), *Objections to Nuclear Defence* (1984), and *Dangers of Deterrence* (1984), are collections of philosophical writings on nuclear war.

There is an immense amount of literature on abortion, though of various philosophical depth. MICHAEL TOOLEY, *Abortion and Infanticide* (1983), is a penetrating study. For contrasting views, see GERMAIN G. GRISEZ, *Abortion: The Myths, the Realities, and the Arguments* (1970); and BARUCH A. BRODY, *Abortion and the Sanctity of Human Life: A Philosophical View* (1975). Another notable treatment is L.W. SUMNER, *Abortion and Moral Theory* (1981). JOEL FEINBERG (ed.), *The Problem of Abortion*, 2nd ed. (1984), is a good collection of essays. For a discussion of sanctity of life issues in general, including both abortion and euthanasia, see JONATHAN GLOVER, *Causing Death and Saving Lives* (1977); and PETER SINGER, *Practical Ethics* (1979). The specific problem of the treatment of severely handicapped infants is discussed in HELGA KUHSE and PETER SINGER, *Should the Baby Live?* (1985).

For a comprehensive textbook on bioethics, see TOM. L. BEAUCHAMP and JAMES F. CHILDRESS, *Principles of Biomedical Ethics*, 2nd ed. (1983). Anthologies of essays on diverse topics in bioethics include SAMUEL GOROVITZ *et al.* (eds.), *Moral Problems in Medicine*, 2nd ed. (1983); and JOHN ARRAS and ROBERT HUNT (comp.), *Ethical Issues in Modern Medicine*, 2nd ed. (1983). JAMES F. CHILDRESS, *Who Should Decide?* (1982), deals with paternalism in medical care; while PETER SINGER and DEANE WELLS, *The Reproduction Revolution: New Ways of Making Babies* (1984), focusses on the new reproductive technology. For the philosophical issues underlying genetic engineering and other methods of altering the human organism, see JONATHAN GLOVER, *What Sort of People Should There Be?* (1984).

(P.Si.)

Europe

Among the continents, Europe is an anomaly. Larger only than Australia, it is a small appendage of the great landmass that it shares with an Asia more than four times its size. Yet the peninsular and insular western extremity of Eurasia, thrusting toward the North Atlantic Ocean, provides—thanks to its latitude and its physical geography—a relatively genial human habitat, and the long processes of human history came to mark off the region as the home of a distinctive civilization. In spite of its internal diversity, Europe has thus functioned, from the time it first emerged in the human consciousness, as a world apart, concentrating—to borrow a phrase from Christopher Marlowe—"infinite riches in a little room."

All the continents are conceptual constructs, but only Europe was not first perceived and named by outsiders. "Europa," as the more learned of the ancient Greeks first conceived it, stood in sharp contrast to both Asia and Libya, the name then applied to the known northern part of Africa. Literally, "Europa" is now thought to have meant "Mainland," rather than the earlier interpretation, "Sunset." It appears to have suggested itself to the Greeks, in their maritime world, as an appropriate designation of the broadening, extensive northerly lands that lay beyond, lands with characteristics but vaguely known; yet these characteristics were clearly different from those inherent in the concepts of Asia and Libya, both of which, relatively prosperous and civilized, were associated closely with the culture of the Greeks and their predecessors. Traders and travelers reported that Europe possessed distinctive physical units, with mountain systems and lowland river basins much larger than those familiar to inhabitants of the Mediterranean region. It also was clear that a succession of climates, markedly different from those of the Mediterranean borderlands, were to be experienced as Europe was penetrated from the south. The spacious eastern steppe and, to the west and north, primeval forests as yet only marginally touched by human occupancy further underlined environmental contrasts. Europe was culturally backward and scantily settled. It was a "barbarian"—that is, a non-Greek—world, its inhabitants making "bar-bar" noises in unintelligible tongues.

The Roman Empire, at its greatest extent in the 2nd century AD, revealed, and imprinted its culture on, much of the face of the continent, while trading relations beyond its frontiers also drew the remoter regions into its sphere. Yet it was not until the 19th and 20th centuries that modern science was able to draw with some precision the geologic and geographic lineaments of the European continent, the peoples of which had meanwhile achieved domination over—and set in motion vast countervailing movements among—the inhabitants of much of the rest of the globe.

As to the territorial limits of Europe, while these seem clear on its three seaward flanks, they have been uncertain and hence much debated on the east, where the continent merges, without sundering physical limits, with parts of western Asia. Even to the north and west, many island groups—Svalbard (Spitsbergen), the British Isles, the Faeroes, Iceland, and the Madeira and Canary islands—that are European by culture are included in the continent, although Greenland is conventionally allocated to North America. Further, the Mediterranean coastlands of North Africa and southwestern Asia also exhibit some European physical and cultural affinities, and Turkey and Cyprus, while geologically Asian, possess elements of European culture and may, perhaps, be regarded as parts of Europe. Eastward limits, now adopted by most geographers, assign the Caucasus Mountains to Asia and are taken to run southward along the eastern foot of the Urals and then across the Mugodzhar Hills, along the Emba River, and along the northern shore of the Caspian Sea. West of the Caspian, the European limit follows the Kuma-Manych Depression and the Kerch Strait to the Black Sea.

This conventional eastern boundary, however, is not a cultural, political, or economic discontinuity on the land comparable, for example, to the insulating significance of the Himalayas, which clearly mark a northern limit to South Asian civilization. Inhabited plains, with only the minor interruption of the worn-down Urals, extend from central Europe to the Yenisey River in central Siberia. A relatively homogeneous, highly centralized, Slavic-based civilization dominates much of the territory occupied by the former Soviet Union from the Baltic and Black seas to the Pacific Ocean. This civilization is distinguished from the rest of Europe by legacies of a medieval Mongol-Tatar domination that precluded sharing many of the innovations and developments of European "Western civilization"; and it became further distinctive during the relative isolation of the Soviet period. In partitioning the globe into meaningful large geographic units, therefore, most modern geographers treated the former Soviet Union as a distinct territorial entity, comparable to a continent, that was separate from Europe to the west and from the rest of Asia to the south and east; this distinction undoubtedly will be maintained for Russia, which occupied three-fourths of the Soviet Union. The following discussion of Europe focuses primarily upon the territories and peoples lying west of the Russian border, although note is taken of physical and cultural features shared by the "European" portion of Russia with the rest of the continent.

Europe occupies some four million square miles (10.4 million square kilometres) within the conventional borders assigned to it. This broad territory reveals no simple unity of geologic structure, landform, relief, or climate. Rocks of all geologic periods are exposed, and the operation of geologic forces during an immense succession of eras has contributed to the molding of the landscapes of mountain, plateau, and lowland and has bequeathed a variety of mineral reserves. Glaciation, too, has left its mark over wide areas, and the processes of erosion and deposition have created a highly variegated and compartmentalized countryside. Climatically, Europe benefits by having only a small proportion of its surface either too cold or too hot and dry for effective settlement and use. Regional climatic contrasts nevertheless exist: oceanic, Mediterranean, and continental types occur widely, as do gradations from one to the other. Associated vegetation and soil forms also show continual variety, but little is left of the dominant woodland that clothed most of the continent when humans first appeared.

All in all, Europe enjoys a considerable and long-exploited resource base of soil, forest, sea, and minerals (notably coal), but its people, considerable numerically, as well as technically highly qualified, are increasingly its principal resource. The continent contains a shrinking seventh of the total population of the world, but this represents a collection of people of high skill and initiative. Europe thus supports high densities of population, concentrated in industrialized regions. In manufacture, commerce, and agriculture it still occupies an eminent, if no longer necessarily predominant, position, and, as agriculture increasingly rationalizes its structure, city life is everywhere becoming the norm.

Europe is preeminently the homeland of white peoples. Its early and continuing economic achievements, evidenced by a high standard of living, and its successes in science, technology, and the arts spring from the vigour of its peoples in developing a high civilization, the roots of which lie in ancient Greece and Rome, the Byzantine Empire, and Palestine. Whatever its indebtedness, Europe has always shown its own powers of creativity and leadership: although wracked and exhausted by continued

internal conflict, it has nevertheless advanced sufficiently to leave as its heritage the exploration, colonization, and development of other peoples and regions of the globe, if not always to the benefit of the other peoples and regions.

(W.G.E./T.M.P.)

This article treats the physical and human geography of Europe, followed by discussion of geographic features of special interest. For discussion of individual countries of the continent, see specific articles by name—*e.g.*, ITALY, POLAND, and UNITED KINGDOM. For discussion of major cities of the continent, see specific articles by name—*e.g.*, LONDON, ROME, and WARSAW. The principal articles discussing the historical and cultural development of the continent include EUROPEAN HISTORY AND CULTURE; GREEK AND ROMAN CIVILIZATIONS, ANCIENT; and HOLY ROMAN EMPIRE, THE HISTORY OF THE. Related topics are discussed in such articles as those on religion (*e.g.*, EUROPEAN RELIGIONS, ANCIENT; JUDAISM; and ROMAN CATHOLICISM) and literature (*e.g.*, DUTCH LITERATURE; HOMERIC EPICS; and SPANISH LITERATURE). For further references, see the *Index*.

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PHYSICAL AND HUMAN GEOGRAPHY

Geologic history

The geologic record of the continent of Europe started about three billion years ago and has continued intermittently to the present. It is a classic example of how a continent has grown through time. The Precambrian rocks in Europe range in age from about 3.8 billion to 540 million years. They are succeeded by rocks of the Paleozoic era, which continued to 245 million years ago; of the Mesozoic era, which lasted until 66.4 million years ago; and of the Cenozoic era, which continues to today. The present shape of Europe did not finally emerge until the late Tertiary period, about five million years ago. The types of rocks, tectonic belts, and sedimentary basins that developed throughout the geologic history of Europe strongly influence human activities today.

GENERAL CONSIDERATIONS

Tectonic framework. The tectonic map of Europe shows the distribution of the main tectonic units. The largest area of oldest rocks is the Baltic Shield, which has been eroded down to a low relief; the youngest rocks occur in the Alpine system, which still survives as high mountains. Between these belts are basins of sedimentary rocks that form rolling hills, as in the Paris Basin and southeastern England, or an extensive plain, as in the Russian Platform. The North Sea is a submarine sedimentary basin on the shallow-water continental margin of the Atlantic Ocean. Iceland is a unique occurrence in Europe, because it is a volcanic island situated on the Mid-Atlantic Ridge within the still-opening Atlantic Ocean.

Occurrence of Precambrian rocks

Precambrian rocks occur in three basic tectonic environments. The first is in shields, like the Baltic Shield, which are large areas of stable Precambrian rocks usually surrounded by later orogenic belts. The second is as the basement to a younger cover of Phanerozoic sediments (*i.e.*, deposits that have been laid down since the beginning of the Paleozoic). For example, the sediments of the Russian Platform are underlain by Precambrian basement, which extends from the Baltic Shield to the Ural Mountains, and


National capitals
Country capitals
International boundaries
Canals
Dams
Salt lakes
Glaciers
Swamps and marshes
Salt flats
Spot elevations in metres (1 m = 3.28 ft)
ELEVATION (in metres)
3000
2000
1000
500
200
100
0
Below sea level
ARCTIC
NORWEGIAN SEA
Arctic Circle
ICELAND
Reykjavik
Vatna Glacier
Mount Hvannadalsh 2119
Fontur Point
FAROE ISLANDS (DEN.)
SHETLAND ISLANDS (U.K.)
ORKNEY ISLANDS
HEBRIDES
UNITED KINGDOM
SCOTLAND
Buchan Ness
Ben Nevis 1343
Edinburgh
NORTHERN IRELAND (U.K.)
Belfast
Dublin
IRELAND
IRISH SEA
ISLE OF MAN
Dunsey Head
WALES
ENGLAND
Cardiff
London
Land's End
English Channel
CHANNEL ISLANDS (U.K.)
BRITTANY
Strait of Dover
Thames
Bay of Biscay
Cape Finisterre
CANTABRIAN MOUNTAINS
IBERIAN SPAIN
PENINSULA
PORTUGAL
Lisbon
Tagus
Douro
Madrid
Cape Saint Vincent
Gulf of Cadiz
Strait of Gibraltar
GIBRALTAR (U.K.)
SIERRA MORENA
Guadalquivir
BAETIC CORDILLERA
Mount Mulhacén 3478
PYRENEES
Aneto Peak 3404
ANDORRA
Andorra la Vella
Gulf of Lion
BALEARIC ISLANDS
MEDITERRANEAN SEA
ATLAS MOUNTAINS
ATLANTIC OCEAN
CELTIC SEA
St. George's Channel
NORTH SEA
EUROPEAN PLAIN
FRANCE
MASSIF CENTRAL
CEVENNES
Paris
Loire
Seine
Dardogne
Garonne
Rhône
Lyon
Marseille
Mont Blanc 4808
Mattehorn 4478
Gulf of Genoa
MONACO
LIGURIAN SEA
CORSICA (FR.)
SARDINIA (IT.)
TYRRHENIAN SEA
ITALY
APENNINES
Mount Corno 2912
Rome
VATICAN CITY
Messina 1237
Etna 3323
SICILY
MALTA
Valletta
Gulf of Venice
Adriatic Sea
DINARIC ALPS
ALPS
Lake Constance
Danube
Lake Geneva
Lake Lucerne
Lake Zurich
Lake Maggiore
Lake Lugano
Lake Balaton
Lake Ladoga
Lake Vänern
Lake Vättern
Lake Tornavan
Lake Kenonkaise 2111
Mount Kebnekaise 2111
LOFOTEN ISLANDS
NORWAY
Bellina Pass 2469
JOTUNHEIM MTS.
Oslo
Cape Lindes
Skagerrak
Kattegat
Jutland
Copenhagen
DENMARK
NORTH FRISIAN ISLANDS
EAST FRISIAN ISLANDS
THE NETHERLANDS
Amsterdam
BELGIUM
Brussels
LUXEMBOURG
GERMANY
Berlin
Elbe
Oder
Vistula
Danube
Prague
CZECH REPUBLIC
Vienna
Bratislava
SLOVAKIA
Budapest
HUNGARY
Lake Balaton
Zagreb
CROATIA
BOSNIA AND HERZEGOVINA
Belgrade
Sarajevo
SERBIA AND MONTENEGRO
Tirana
ALBANIA
CORFU
IONIAN SEA
SWEDEN
Gulf of Bothnia
ÅLAND ISLANDS
Stockholm
GOTLAND
BALTIC SEA
BORNHOLM (DEN.)
KALININGRAD (RUSSIA)
POLAND
LITTLE POLAND UPLANDS
Mount Carlsen 2600
Mount Gerlach 2655
Bay of Biscay
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ARCTIC OCEAN
BARENTS SEA
KOLGUYEV ISLAND
KOLA PENINSULA
Kanin Peninsula
WHITE SEA
TIMAN RIDGE
URAL MOUNTAINS
Mount Narodnaya 1,895
Ob
Irtysh
Pechora
Mezen
Severnaya Dvina
Northern Dvina
Vychegda
Kama
Kama Reservoir
Ufa
Belaya
Ural
Iriklinskoye Reservoir
Samara
Samara Reservoir
Volga
Kuybyshev Reservoir
Saratov Reservoir
Volgograd Reservoir
Zhiguli Hills
Volga Hills
Zhiguli
Don
Tsimlyanskoye Reservoir
Tsimlyansk Reservoir
Manych
Kuma-Manych Depression
Kuma
Terek
Sulak
Caspian Depression
Caspian Sea
Caucasus
Kura
Gorgan Plain
Gorgan Gulf
Mangyshlak Peninsula
Ural Mountains
Mugodzhary Hills
Aral Sea
Lake Sarykamys
Kazakstan
Uzbekistan
Russian Plain
Central Russian Upland
Valdai Hills
Moscow
Rybinsk Reservoir
Nizhniy Novgorod Reservoir
Oka
Western Dvina
Dnieper
Pripet Marshes
Pripet
Desna
Seym
Donets
Donetsk
Kremenchug Reservoir
Dniester
Kakhovka Reservoir
Kakhovka
Sea of Azov
Kerch Strait
Kuban
Crimean Peninsula
Black Sea
Bosporus
Lake Van
Turkey
Lake Tuz
Dardanelles
Aegean Sea
Greece
Athens
Peloponnese
Rhodes
Cyprus
Nicosia
Crete
Finland
Lake Inari
Lake Saimaa
Lake Onega
Lake Ladoga
Lake Pielinen
Helsinki
Gulf of Finland
Tallinn
Estonia
Saaremaa
Lake Peipus
Latvia
Riga
Lithuania
Vilnius
Belarus
Minsk
Warsaw
Ukraine
Kiev
Moldova
Chisinau
Romania
Transylvanian Alps
Bucharest
Danube
Balkan Mountains
Bulgaria
Sofia
Macedonia
Rhodope Mountains
Athlan Mountains
Alps
Scale 1:17,917,000
1 inch equals approx. 283 miles
0 100 200 300 mi
0 50 150 250 350 450 km
Bonne's Projection



Structural features of Europe.

Precambrian rocks underlie the Phanerozoic sediments in southeastern England. The Ukrainian Massif is an uplifted block of Precambrian basement that rises above the surrounding plain of younger sediments. The third is as relicts in younger orogenic belts. For example, there are Precambrian rocks in the Bohemian Massif that are one billion years old and rocks in the Channel Islands in the English Channel that are 1.6 billion years old, both of which are remnants of the Middle Proterozoic era within the late Paleozoic Hercynian belt. In the Hercynian belt in Bavaria, detrital zircons have been dated to 3.84 billion years ago, but the source of these rocks is not known.

Paleozoic sedimentary rocks either occur in sedimentary basins like the Russian Platform—which has never been affected by any periods of orogenesis and thus has sediments that are still flat-lying and fossiliferous—or occur within orogenic belts, such as the Caledonian and Hercynian, where they have commonly been deformed by folding and thrusting, partly recrystallized, and subjected to intrusion by granites.

Mesozoic–Cenozoic sediments occur either in a well-preserved state in sedimentary basins unaffected by orogenesis, as within the Russian Platform and under the North Sea, or in a highly deformed and metamorphosed state, as in the Alpine system.

Chronological summary. The geologic development of Europe may be summarized as follows. Archean rocks (those more than 2.5 billion years old) are the oldest of the Precambrian period and crop out in the northern Baltic Shield, Ukraine, and northwestern Scotland. Two major Proterozoic orogenic belts (*i.e.*, between 2.5 billion and 540 million years old) also extend across the central and southern Baltic Shield. Thus, this shield has a composite origin, containing remnants of several Precambrian orogenic belts.

About 540 to 500 million years ago a series of new oceans opened, and their closure gave rise to the Caledonian, Hercynian, and Uralian orogenic belts. There is considerable evidence which suggests that these belts developed by plate-tectonic processes, and they each have a history that lasted hundreds of millions of years. Formation of these belts gave rise to the supercontinent of Pangaea; its fragmentation at the beginning of the Middle Triassic epoch (about 240 million years ago) gave rise to a new ocean, the Tethys Sea. Closure of this ocean early in the Tertiary period, about 50 million years ago, by subduction and plate-tectonic processes led to formation of the Alpine orogenic system, which extends from the Atlantic to Turkey and contains many separate orogenic belts (which remain as mountain chains), including the Pyrenees, Baetics, Atlas, Swiss-Austrian Alps, Apennines, Carpathians, Dinaric Alps, and Taurus and Pontic mountains. During the time that the Tethys was opening (about 180 million years ago), the Atlantic Ocean also began to open; the structure and age of the seafloor between Iceland and the continental margin of the British Isles and Norway are well known. The Atlantic is still opening along the Mid-Atlantic Ridge under the ocean, with Iceland constituting an area of the ridge that is raised above sea level. The youngest tectonic activity in Europe is represented by the present-day volcanic eruptions in Iceland; volcanoes, such as Etna and Vesuvius; and earthquakes, as in the Aegean and Turkey in the Alpine system, which result from current stresses between Europe and Africa.

Alpine orogenic system

STRATIGRAPHY AND STRUCTURE

The Precambrian. This major period of geologic time can be subdivided into the older Archean and the younger Proterozoic eons, the time boundary between them being 2.5 billion years ago. Compared with most of the other continents, Europe has few exposed Archean rocks. Some granitic gneisses, which are more than three billion years old, crop out in the northern Baltic Shield, the Ukrainian Massif, and northwestern Scotland. These rocks were recrystallized at a depth of about 12 miles (20 kilometres) in the Archean crust, but their tectonic environment is poorly understood. The Baltic Shield exhibits successively younger orogenic belts toward the south, from the Archean relicts in the north to the Late Proterozoic belt of the Sveconorwegian in southwestern Norway. A major orogenic belt, the Svecofennian, developed in the Early Proterozoic era (2.5 to 1.6 billion years ago); it now occupies the bulk of the Baltic Shield, especially in Finland and Sweden, where it extends from the Kola Peninsula to the Gulf of Finland near Helsinki. The Sveconorwegian is a north–south-trending orogenic belt that developed between 1.2 billion and 850 million years ago. It occupies southern Norway and the adjacent area of southwestern Sweden between Oslo and Göteborg. On its northern side it has been reactivated almost beyond recognition within the Caledonian orogenic belt. The Ukrainian Massif and the small Laxfordian belt in northwestern Scotland consist mainly of granitic rocks and highly deformed and metamorphosed schists and gneisses that originally were sediments and volcanics, their age similar to that of the Svecofennian belt. In northwestern Scotland there is a north–south-trending belt of red sandstones and conglomerates belonging to the Torridonian group that is about one billion years old; these sediments may be the erosional products or molasse of a 1.2-billion-year-old orogenic belt, of which there are a few relicts within the Paleozoic Caledonian belt of Scotland. The Bohemian Massif is a diamond-shaped block in the heart of Europe, which has been heavily affected by the late Paleozoic Hercynian orogeny.

The Bohemian Massif

Many of the rocks formed in the Late Archean (about 2.7 billion years ago) or Early Proterozoic (Svecofennian times) or later in the Proterozoic (about one billion years ago) were strongly deformed in several Precambrian orogenies and thus are now schists, gneisses, and amphibolites, accompanied by a variety of granites. Near the end of the Precambrian—about 800 to 540 million years ago—there was widespread deposition of conglomerates, sandstones, clays, and some volcanic sediments, which make up the Eocambrian (or Vendian) group; these were derived from the erosion of uplifted Precambrian mountains. They are well known for two features: First is their glacial sediments, which were deposited at a time of worldwide glaciation; they occur in northwestern Scotland (Islay Island), western Ireland, Norway (Finnmark and West Spitzbergen), Sweden, France (Normandy), and the Czech Republic (Bohemian Massif). Second is the occurrence of impressions of soft-bodied organisms, such as seaweed, jellyfish, and worms, which represent the beginnings of Metazoan life before the explosion of life-forms with hard parts for skeletons that became abundant in the Early Cambrian.

These impressions occur in Charnwood Forest in central England, southern Wales, northern Sweden, Ukraine, and several localities in the Russian Platform. The Precambrian rocks of Europe provide a rich source of economic minerals that sustain human activities, such as major iron ore deposits at Kiruna in northern Sweden and Kryvyy Rih (Krivoy Rog) in Ukraine; tin deposits associated with granites in Finland; extensive copper–nickel sulfide ores across Finland and in Sweden; and magnetite ores containing vanadium and titanium in northern Finland.

The Paleozoic era. The Paleozoic (540 to 245 million years ago) tectonic geology of Europe can be divided into two parts: the major orogenic belts of the Caledonian (or Caledonides), the Hercynian (or Hercynides), and the Uralian (or Uralides); and the undisturbed, mostly subsurface (and poorly known) Paleozoic sediments in the triangular area between these belts in the Russian Platform.

Caledonian orogenic belt. The major factor that controlled the early mid-Paleozoic development of Europe was the opening and closing of the Iapetus Ocean, which gave rise to the Caledonian orogenic belt that extends from Ireland and Wales through northern England and Scotland to western Norway and northward to Finnmark in northern Norway. The belt is confined between the stable blocks of the Baltic Shield and the Precambrian belt of northwestern Scotland. Remnants of the Iapetus seafloor are seen in ophiolites at Ballantrae in the Strathclyde region of Scotland, and near Bergen in Norway. During the Cambrian period (540 to 505 million years ago) widening of the Iapetus gave rise to extensive shelf seas on the bordering continents, which deposited a thin cover of limestone and shale with a remarkable diversity of fossils of numerous marine invertebrates. The existence of this sea can be demonstrated by the presence of trilobites and graptolites in northern Scotland, which was on one side, that are significantly different from those in central England and southern Norway, which were on the other. In the Ordovician period (505 to 438 million years ago) the sea began to close by subduction, giving rise to major magmatic belts with lavas and tuffs in the Lake District of northern England and in Snowdonia National Park in northern Wales—where there is associated gold and copper mineralization—and to many granites in the Highlands of Scotland. In the Silurian period (438 to 408 million years ago) the Iapetus Ocean closed, with the result that the bordering continental blocks collided, giving rise to deformation, metamorphism, and the orogeny of the Caledonian belt. In the Late Silurian, early land plants and the first freshwater fish appeared in lakes on the belt. The rifts of the Orkney Basin developed in the Devonian period (408 to 360 million years ago) on top of the thickened and unstable crust of the Caledonian orogenic belt in a manner comparable to the Quaternary rifts of Tibet (*i.e.,* those that have appeared in the past 1.6 million years) that have a crust thickened by the Himalayan orogeny of the Tertiary period (66.4 to 1.6 million years ago). Erosion of the uplifted mountain belt in the Devonian led to deposition of sandstones and conglomerates in basins over a wide region from the British Isles to the western Russian Platform, often called the Old Red Sandstone continent.

Marine fossil deposits

Hercynian orogenic belt. The Hercynian, or Variscan, orogenic belt evolved during Devonian and Carboniferous times, from about 408 to 286 million years ago. The belt extends from Portugal and western Spain, southwestern Ireland, and southwestern England in the west through the Ardennes, France (Brittany, Massif Central, Vosges, and Corsica), Sardinia, and Germany (Oden Forest, Black Forest, and Harz Mountains) to the Czech Republic (Bohemian Massif). The orogeny was formed by plate-tectonic processes that included seafloor spreading, continental drift, and the collision of plates. Remnants of the original ocean floor are preserved as ophiolites in the Harz Mountains and in the Lizard Peninsula of southwestern England. In the Devonian a continental margin ran along the north side of the belt in Devon and Cornwall (England) on which extensive sandstones derived from the continent were deposited. In the Carboniferous period shallow-water limestones were laid down in the area of the Pennines of England on a shelf or carbonate bank; this formation passes southward into deeper-water shales of the Culm Trench of southwestern England, within which are found the pillow lavas, gabbros, and serpentinites of the Lizard ophiolite. In Brittany there is an island arc with lavas and granites that resulted from subduction of the ocean floor. The main Hercynian suture zone of the collided plates extends from the south side of Brittany to the Massif Central. Throughout much of Europe there is evidence of extensive thrusting, implying that there was appreciable thickening of the continental crust and the formation of a Tibetan-style plateau across the Hercynian orogeny. The thickening led to melting of the lower crust and the formation of large numbers of Late Carboniferous granites, especially in the Massif Central. The plateau became overly thick and unstable, and this caused the formation of rifts that developed into coal-bearing basins—as in Silesia (Poland) and the Massif Central—in the Late Carboniferous and Permian periods (*i.e.,* between about 320 and 245 million years ago). The varied tectonic development of the Hercynian orogeny gave rise to widespread mineral deposits in many environments, which have been exploited in the economic development of many countries. Lead and zinc deposits occur in shelf carbonate sediments in Ireland and the Pennines of England; there are deposits of copper, lead, and zinc sulfides that formed in rifts in Silesia (Poland and eastern Germany) and at the Riotinto Mines in southwestern Spain; and deposits of tin, tungsten, and uranium are associated with crustal melt granites in Cornwall, the Massif Central, and Spain and Portugal.

Main suture zone

Uralian orogenic belt. The Uralian orogenic belt, which forms the traditional eastern boundary of Europe, extends for about 2,175 miles (3,500 kilometres) from the Aral Sea to the northeasternmost tip of Novaya Zemlya in the Arctic Ocean. It encompasses the Mughalzhar Hills north of the Aral Sea, the Ural Mountains proper, the Pay-Khoy Ridge, and Novaya Zemlya. The belt developed late in the Paleozoic as a result of collision between Asia and Europe. The earliest rifts in old Precambrian basement rocks began in the Late Cambrian–Early Ordovician, about 500 million years ago, and these developed into the floor of a new ocean. Island arcs formed in the Silurian period, and countless ophiolitic slabs of ocean floor were thrust onto the continental margins. In Devonian times a considerable amount of thrusting and metamorphism occurred, and the final parts of the ocean floor were subducted (*i.e.,* thrust under continental masses); the result of this activity was that in the Permian there was a final collision between the continents of Europe and Asia that gave rise to the Uralian orogenic belt. In the Permian there was widespread deposition of limestones followed by red sandstones, which were derived by erosion of the mountains. In the 1840s the British geologist Sir Roderick Murchison coined the term Permian System, named for the city of Perm. The Ural Mountains are rich in mineral deposits, which are associated with the major ophiolitic slabs of ocean floor distributed along the chain.

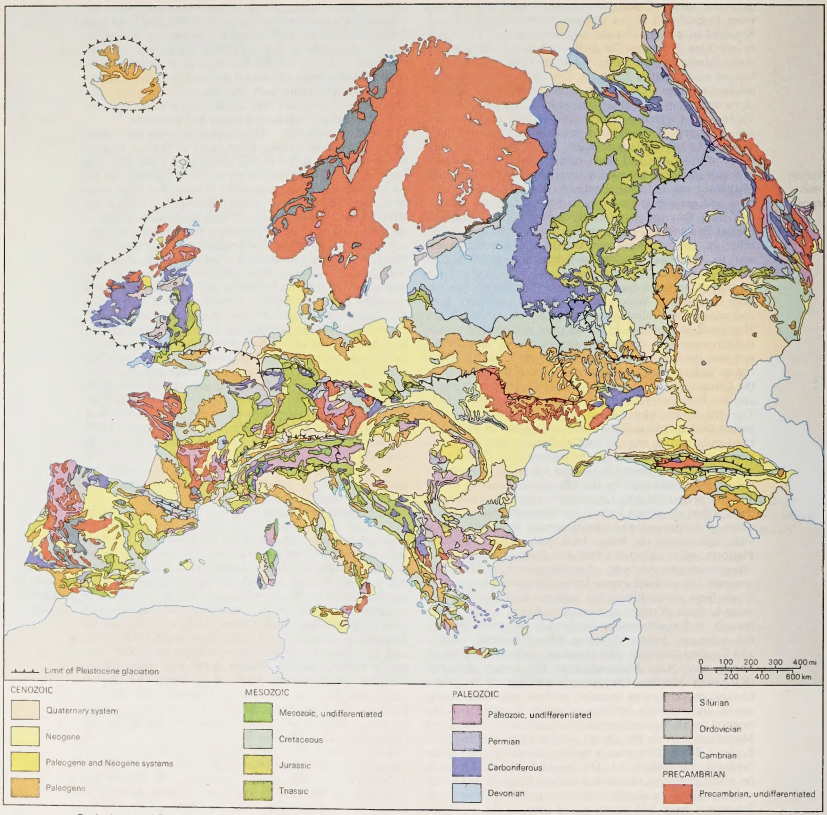
The Mesozoic and Cenozoic eras. During the Mesozoic era a new ocean, the Tethys, evolved in what is now southern Europe, and during the Cenozoic era this ocean was destroyed by subduction, with the result that many small plates collided. These events gave rise to the present-day tectonic mosaic that extends eastward from the Atlas Mountains of North Africa, the Baetic Cordillera of southern Spain, and the Pyrenees via the Alps of maritime France, Switzerland, and Austria to the Carpathians, the Apennines, the Dinaric Alps, the Alpine belt of Bulgaria, and the Taurus and Pontic mountains of Turkey and finally to the Caucasus. Within these belts must also be included the Pannonian Basin of Romania and the Algerian (or Balearic), Alborán, Tyrrhenian, and Adriatic basins of the Mediterranean Sea. The main cause of this Alpine orogeny during the Cenozoic was the northward compression of Africa into Europe.

Tectonic mosaic of southern Europe

The first rifting of the older continent began with salt and evaporite deposition in lakes in rift valleys in the Early Triassic (245 to 240 million years ago). By 220 million years ago, in the Late Triassic, the continental margins of the new, narrow Tethys were commonly covered by shallow water over fossiliferous, carbonate shelf sediments.

During the Middle Jurassic, about 180 million years ago, these carbonate shelves began to fragment, and in the Cretaceous (144 to 66.4 million years ago) the ocean floor was subducted in many places. This gave rise to volcanic island arcs, such as those of present-day Indonesia, and slabs of the Tethys ocean floor were thrusted as ophiolites onto the continental margins. Extensive remnants of these ophiolites can be seen today, especially in the northern Apennines and in the Balkan region, Turkey, and Cyprus. Collisions between many of the continental microplates took place in the Eocene–Oligocene (about 58 to 24 million years ago) epochs. For example, the Iberian Peninsula rotated to give rise to the Pyrenees, the Italian Peninsula drove northward and compressed into Europe, causing growth of the Swiss-Austrian Alps, and Anatolia moved westward and gave rise to the Aegean arc and the mountains of Greece. It is interesting to consider that it was the opening of the Red Sea that caused the Arabian Peninsula to slide northward along the fault defined by the Dead Sea and the Jordan Valley and in so doing to form at its front the Zagros Mountains of Iran, which, in turn, pushed Anatolia westward and caused the deformation in Greece. This scenario illustrates the interlinking and interdependence of all these movements and structures in Europe with those outside the continent. In the Late Miocene (11.2 to 5.3 million years ago) many of the early Mediterranean basins (*e.g.*, Balearic, Tyrrhenian, Ionian, and Levantine) became isolated from the main Atlantic and Indo-Pacific oceans, and in these basins were laid down huge deposits of salt and gypsum in evaporites up to more than a mile thick. There are several important economic mineral deposits in the European Alpine system that can be related to the several stages of geologic evolution described above. Lead and zinc deposits occur in Triassic shelf limestones at Blei Hill in western Germany. Chromite ores are found in the ophiolites of the Balkan region and Turkey. Copper ores formed in pillow-bearing basaltic lavas of the Tethyan ocean floor; copper mines

Mineral deposits in the Alps



Geologic map of Europe.

have been worked since antiquity in Cyprus, which lent its name to this element. The Tethys, however, was a relatively narrow ocean, and thus its limited subduction was not able to give rise, for example, to many granites and volcanic rocks, which might have contained useful mineral deposits. Active seismic disturbances expressed as earthquakes are a reflection of the continuing compression between several of the European microplates; they are common in the Atlas Mountains, the island arc of the South Aegean, Greece, the island arc of the Tyrrhenian Sea in southern Italy, Turkey, and the Caucasus Mountains.

The North European and Russian platforms. An approximately triangular area is described between the Caledonian orogeny in the west, the Hercynian orogeny and the Alps in the south, and the Urals in the east. This area includes the Russian and North European platforms and the North Sea. Within this area the Phanerozoic sedimentary rocks are either undeformed or only weakly deformed, and thus this area contrasts with the surrounding orogenic belts described above where such sediments are strongly deformed. Thus, throughout much of the extensive Russian Platform the Paleozoic, Mesozoic, and Cenozoic sediments have escaped the effects of the surrounding orogenies, and they are almost as horizontal as when they were laid down. Farther west in the portion of the North European Platform that includes southeastern England and northern France, Mesozoic and early Cenozoic sediments have been weakly deformed into anticlines and synclines by the Tertiary deformation of the Alpine orogenic belt to the south. This took place at a shallow level of the crust, and the sediments are still unmetamorphosed. Thus, the best place to find beautifully preserved Phanerozoic fossils is in this central triangular area of Europe. Under the North Sea there are gas reserves in Permian and Triassic sediments, and there are major oil reservoirs in Jurassic sediments. This is a subsided fragment of the continental margin of Europe flooded with water from the melted glaciers of the last Ice Age.

The Tertiary igneous province of northwestern Britain. From about 61 to 52 million years ago (early in the Tertiary) there were important igneous extrusions and intrusions in northwestern Britain. In Northern Ireland and northwestern Scotland, basaltic lava flows (*e.g.*, the Giant's Causeway and the northern part of the isle of Skye) are associated with northwest–southeast-trending basaltic dikes and many plutonic complexes, which are probably the roots of volcanoes. The dikes extend southeastward across northern England and continue under the North Sea. Related lavas occur in the Faeroe Islands, belonging to Denmark. These igneous rocks formed in the faulted and thinned continental margin of northwestern Europe contemporaneously with the rifting and seafloor spreading that gave rise to the Atlantic Ocean.

Basaltic lava flows and dikes

Iceland. The Mid-Atlantic Ridge is a major plate boundary separating the North American and the Eurasian plates, and it extends through the centre of Iceland. Along this ridge the Atlantic Ocean is still growing, and on Iceland this activity is expressed as major rifts, volcanoes, and steam geysers. The entire island is made of lavas, the oldest of which on the northwestern coast came from eruptions about 16 million years ago. Iceland thus preserves a unique record of the last stages of development of one of the world's major accreting plate boundaries, most of which is elsewhere submarine. (B.F.W.)

The Quaternary period. The Pleistocene epoch occupies the Quaternary period (the last 1.6 million years), with the exception of the last 10,000 years, which are called the Holocene epoch. Although the precise causes of the Ice Ages that mark the Pleistocene are controversial, it is known that prior to this glaciation northern Europe had risen to a much higher elevation than now and that ice formed to great depths there, as in the rest of the Atlantic landmass and the Alpine areas. The Pleistocene was punctuated by warm interglacial periods separating glacial advances; during its latter part, humans occupied niches in the more southerly parts of the continent.

Glaciers are the most powerful engines provided by nature for the transport—by plucking or quarrying—of large masses of rock, and certainly the European glaciers transformed the physique both of their source areas and of the lands to which they moved. Many physical forms of northern and Alpine Europe resulted from glacial erosion, supplemented by weathering, and the surfaces of areas where the glaciers eventually withered away consisted of masses of transported material. Southern Scandinavia, southern Finland, the Swiss Plateau, and the North European Plain were thickly plastered with a variety of forms, including boulder-studded clay, gravels, sands, and the windblown deposits known as loess. New drainage patterns were formed. The melting of so much ice raised the level of the oceans by an estimated 320 or more feet, while former ice-clad lands, including the North Sea area, began to rise isostatically. It was not until quite late in the Holocene that the northern seas of Europe—the Irish, North, and Baltic—took, by stages, their present shape.

The modern geologic framework. Although the exposed rocks of Europe are obscured increasingly by the works of humans, and while detailed understanding of rock patterns present challenges even to the expert, the major formations of the continent are clear. In the north lie wide areas of ancient worn-down rocks, stripped of soil by the glaciers but compensated in some measure by the coastal plains created by uplift. In contrast, southern Europe, although incorporating such relicts as massifs of Paleozoic rocks, is essentially a youthful world, not yet fully fashioned, as evidenced by continuing seismic disturbances. Eastern Europe, based on the vast Russian Platform, is a stable world still young in surface, since the floor of its shield rocks is deeply concealed beneath Mesozoic and Tertiary deposits, above which glacial material covers the northern half and loess deposits enrich the south. Although in scale this platform is a continental area, river development facilitates access to inland seas in both the north and the south. Ancient rocks, lying near the surface, offer mineral wealth, and the former Volga–Ural seas have left a residue of petroleum and mineral salts. For the rest, western and central Europe show great diversity of landforms and landscape as well as varied soil and mineral resources. Alpine ranges in the south and southeast combine high altitude and relief with scenic attractions and—more importantly—with high precipitation and water dispersion. Highland areas, remnants of faulted Hercynian belts surrounded by younger strata, provide another type of wooded landscape, with their contained coalfields. Iceland has the youngest landscape of Europe, with its spectacular semiactive volcanoes, high waterfalls, extensive glaciers, and steam geysers. Lastly, lowlands, of great human value, recall their varied origins—former sea and lake basins; lowlands of glacial deposition; parts of eroded synclinal structures; and alluvial and marine plains won from the sea by isostasy or, as exemplified by the Dutch polders, by the work of humans. (W.G.E./B.F.W.)

Differences between northern and southern Europe

The land

A contrast exists between the configuration of peninsular (or western) Europe, and eastern Europe, which is a much larger and more continental area. A convenient division is made by a line linking the base of the Jutland Peninsula with the head of the Adriatic Sea. The western part of the continent clearly has a high proportion of coastline with good maritime access and often with inland penetration by means of navigable rivers. Continental shelves—former land surfaces that have been covered by shallow seas—are a feature of peninsular Europe, while the coasts themselves are both submerged or drowned, as in southwestern Ireland and northwestern Spain, and emergent, as in western Scotland and southern Wales where raised former beaches are in evidence. East of the Vistula River, Europe's expansive lowlands have something of the scale and character of those of northern Asia, but the continent also comprises numerous islands, some—notably the Faeroes and Iceland—located at a distance from the mainland. Fortuitously, Europe has no continuous mountain obstacle aligned north–south, corresponding, for example, to the Western Cordillera of North America and the Andes of South America, that would limit access into western Europe from the ocean.

Peninsular and eastern Europe

RELIEF

Elevations. Lands lying at high altitude can, of course, be lands of low relief, but on the European continent relief tends to become more rugged as altitude increases. The greater part of Europe, however, combines low altitude with low relief. Only hill masses less than 800 feet (240 metres) in height rise gently within the East European (or Russian) Plain, which continues northward into Finland, westward into the North European Plain, and southward in the Romanian, Bulgarian, and Hungarian plains. The North European Plain, common to much of Poland, northern Germany, and Denmark, broadens in western France and continues, across the narrow seas, in southeastern Great Britain and Ireland. The major peninsula of Scandinavia is mostly upland and highland, with its relief greatest at the descent to the Norwegian fjords and the sea; eastward and southward the seas are approached more gently. The highest points reached in Norway and Sweden are, respectively, Galdhø Peak (8,100 feet) and Mount Kebne (6,926 feet). Iceland's highest peak is Mount Hvannadals, at 6,952 feet, while Ben Nevis, the highest summit in Great Britain, stands at a height of only 4,406 feet. Greater relief is found in those areas in the heart of western and central Europe where uplifted and faulted massifs survive from the Hercynian orogeny. The worndown Ural Mountains also belong in this category, and their highest point, Mount Narodnaya (6,217 feet), corresponds approximately to that of the Massif Central in south central France. Altitudes in these areas are mainly between about 500 and 2,000 feet, and many steep slopes are to be seen.

The highest altitudes and the most rugged relief of the European continent are found farther south, where the structures of the Cenozoic orogeny provide mountain scenery. In the Alps, Mont Blanc rises to a height of 15,771 feet (4,807 metres), which is the highest point on the continent. In the Pyrenees and the Sierra Nevada of Spain, the highest of the peaks exceed 11,000 feet. The Apennines, Dinaric Alps, and Balkan Mountains, as well as the arc-shaped Carpathian Mountains and their southern portion, the Transylvanian Alps, also exhibit high altitudes. The highest peaks in these ranges are Mount Corno (9,554 feet) in the Abruzzi Apennines, Bobotov Kuk (8,274 feet) in the Dinaric Alps, Mount Botev (7,795 feet) in the Balkan Mountains, Gerlachovský Štít (Gerlach; 8,711 feet) in the Western Carpathians, and Mount Moldoveanu (8,347 feet) in the Transylvanian Alps. Above all, in southern Europe—Austria and Switzerland included—level, low-lying land is scarce, and mountain, plateau, and hill landforms dominate. The lowest terrain in Europe, virtually lacking relief, stands at the head of the Caspian Sea; there the Caspian Depression reaches some 95 feet (29 metres) below sea level.

Physiographic units. Four broad topographic units can be simply, yet usefully, distinguished in the continent of Europe: coastal and interior lowlands, central uplands and plateaus, the northwestern highlands, and southern Europe.

Lowlands. More than half of Europe consists of lowlands, standing mostly below 600 feet but infrequently rising to 1,000 feet. Most extensive between the Baltic and White seas in the north and the Black, Azov, and Caspian seas in the south, the lowland narrows westward, lying to the south of the northwestern highlands; it is divided also by the English Channel and the mountains and plateaus of central Europe. The Danubian and northern Italian lowlands are thus mountain-ringed islands. The northern lowlands are areas of glacial deposition and, accordingly, their surface is diversified by such features as the Valdai Hills of western Russia; by deposits of boulder clay, sands, and gravels; by glacial lakes; and by the Pripet Marshes, a large ill-drained area of Belarus (Belorussia) and Ukraine. Another important physical feature is the southeast–northwest zone of windblown loess deposits that have accumulated from eastern Britain to Ukraine. This *Börde* (German: "edge") belt lies at the northern foot of the Central European Uplands and the Carpathians. Southward of the limits of the northern ice sheets are vales and hills, with the Paris and London basins typical examples. Superficial rock cover, altitude, drainage, and

The northern lowlands



Major physiographic regions of Europe.



Scenic fjord, or sea inlet, winding deep into the mountainous coast of western Norway.
Bob and Ira Spring

soil have sharply differentiated these lowlands—which are of prime importance to human settlement—into areas of marsh or fen, clay vales, sand and gravel heaths, or river terraces and fertile plains.

Central uplands and plateaus. The central uplands and plateaus present distinctive landscapes of rounded summits, steep slopes, valleys, and depressions. Examples of such physiographic features can be found in the Southern Uplands of Scotland, the Massif Central of France, the Meseta Central of Spain, and the Bohemian Massif. Routes detour around, or seek gaps through, these uplands—whose German appellation, *Horst* ("thicket"), recalls their still wooded character, while their coal basins give them great economic importance. The well-watered plateaus give rise to many rivers and are well adapted to pastoral farming. Volcanic rocks add to the diversity of these regions.

Northwestern highlands. The ancient, often mineral-laden rocks of the northwestern highlands, their contours softened by prolonged erosion and glaciation, are found throughout much of Iceland, Ireland, and in northern and western Britain and Scandinavia. These highland areas include lands of abundant rainfall—which supplies hydroelectricity and water to industrial cities—and provide summer pastures for cattle. The land in these areas, however, is of little use for crops. The coasts of the northwestern highlands—and in particular the fjords of Norway—invite maritime enterprise.

Southern Europe. A world of peninsulas and islands, southern Europe is subject to its own climatic regime, with fragmented but predominantly mountain and plateau landscapes. Iberia and Anatolia (Turkey) are extensive peninsulas with interior tablelands of Paleozoic rocks that are flanked by mountain ranges of Alpine type. The restricted lowlands lie within interior basins or fringe the coasts; those of Portugal, Macedonia, Thrace, and northern Italy are relatively large. Runoff from the Alps furnishes much water for electricity-generating stations, as well as for the flow regimes of major rivers.

Peninsulas and islands of the south

Detailed discussion of the Alps, Apennines, Carpathian Mountains, European Plain, Pyrenees, and Ural Mountains can be found in *European geographic features of special interest* at the end of this article.

DRAINAGE

Topographic influences. The drainage basins of most European rivers lie in areas originally uplifted by the Caledonian, Hercynian, and Alpine mountain-building periods that receive heavy precipitation, including snow. Some streams, notably in Finland and from southern Poland to west central Russia, have their sources in hills of Tertiary rocks, while others, including the Thames and Seine rivers, derive from hill country of Mesozoic rocks. Drainage is directly, or via the Baltic and the Mediterranean seas, to the Atlantic and the Arctic oceans and to the enclosed Caspian Sea.

Drainage basins

The present courses and valley forms of the major rivers result from an intricate history involving such processes as erosion by the headstream, downcutting, capture of other rivers, faulting, and isostatic changes of land and sea levels. The Rhine, for example, once drained to the Mediterranean before being diverted to its present

Josef Muench



Coastal landscape of submerged mountains and resulting islands and bays characteristic of Greece along the Aegean Sea.

northerly course. The courses of many rivers—notably those of Scandinavia and the North European Plain—have been shaped since the Pleistocene epoch. While the Alps, Apennines, and Carpathians provide watersheds, other mountain ranges have been cut through by rivers, as by the Danube at Vienna, Budapest, and the Iron Gate and by the Olt (in Romania). In the East European Plain the rivers are long and flow sluggishly to five seas. In western, central, and eastern Europe, rivers are largely "mature"; *i.e.*, their valleys are graded, and their streams are navigable. Northern and southern Europe, in contrast, present still "youthful" rivers, as yet ill-graded and thus more useful for hydroelectricity than for waterways. The Atlantic rivers have scoured estuaries widening seaward, while, in the Baltic, Mediterranean, and Black seas, with minimum tidal influences, deltas and spits have been created. The upper Dnieper (Dnepr), since post-Pleistocene times, has failed to drain effectively the low area of minimal relief known as the Pripet Marshes.

Hydrology. The water volume of, and discharge from, the rivers of Europe are governed by factors that include local conditions of rainfall, snowmelt, and rock porosity. In consequence, the rivers in the western area have more volume and higher discharges in the winter season and are at their lowest in summer. In areas of mountainous and continental climate, thanks to the runoff of snowmelt, the rivers are highest in spring and early summer. The longer rivers of the continent, notably the Rhine and the Danube, have complex regimes, since their basins extend into areas of contrasting climate. Although embanking measures have reduced the problem, flooding is a continued threat. Thus, the rivers of European Russia are liable to flood with the spring thaw; oceanic rivers, after heavy or prolonged rain over the whole basin; and Alpine rivers, when the warm foehn wind rapidly melts the snow. In the Mediterranean region some rivers—as in peninsular Greece—tend to dry up in summer through a combination of scant rainfall, evaporation, and porous limestone beds. In the Abruzzi region of central Italy, however, heavy rainfall, mainly in winter, permeable and porous rocks within the basin, and abundant snow combine to regulate the river regimes.

Flood danger

The Rhône achieves a steady flow throughout the year, deriving a high input from the Cévennes Mountains—which experience heavy winter rain—plus abundant spring and summer snowmelt from the Alps via Lake Geneva. The Rhine and Danube tap supplies from the Alps in spring and summer, and the Rhine, especially, taps areas of winter rainfall maximum. The Volga has its highest water in spring and early summer, thanks to snowmelt, and falls to a summer low. The Saône, lying within the oceanic climatic area, tends to have a good flow yearround. The winter freeze of the east only rarely seriously affects the Danube and western European rivers.

Lake systems and marshes. Lakes cover less than 2 percent of Europe's surface and occur mostly in areas subjected to Pleistocene glaciation. The Scandinavian Peninsula and the North European Plain account for four-fifths of the area of lakes; and in Finland lakes cover one-fifth of the surface. The other major zones of lakes lie marginal to the Alpine system, while Scotland, too, has its many "lochs" and Ireland its "loughs." Lakes survive where the inflow of water exceeds loss from evaporation and outflow and should eventually disappear through alluvial accumulation. Their origins lie in the glacial excavation of softer rocks, in the building of dams by morainic material, and in tectonic, or deforming, forces, which may create depressions. This second explanation clearly applies to Alpine lakes; to many of those in the British Isles, including the small but scenic ones of the Lake District of England; and also to those of central Sweden. Volcanic crater lakes are found in central Italy, and small lakes of the lagoon type are found along the Baltic and Mediterranean, where spits have lengthened parallel to the coast and hence cut off sea access.

A well-developed zone (the *Marschen*) has formed along the low-lying and reclaimed marshes along the North Sea in Germany and The Netherlands, and characteristically the estuaries of Europe's tidal rivers are edged by flat alluvial marshes. Fens, as exemplified by the polders in The Netherlands and the lowlands in eastern England, are made up of either alluvium or peat and stand too low to be drained effectively, except by continuous pumping. The continent's largest marshland is the Pripet Marshes of Belarus and Ukraine.

The *Marschen* zone

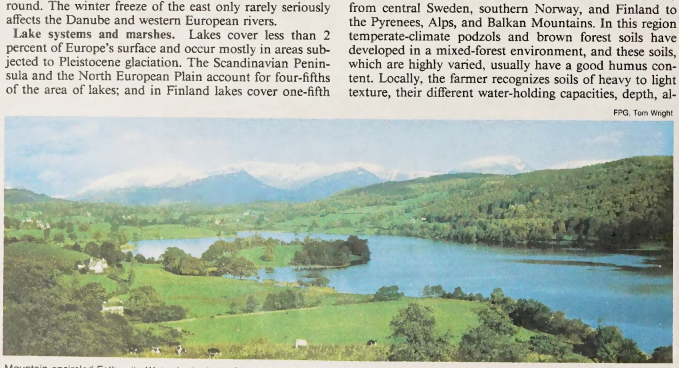
Detailed discussion of Europe's drainage systems can be found in *European geographic features of special interest* at the end of this article. The discussion for western Europe includes the Rhine, Rhône, and Seine rivers. The discussion for central Europe includes the Danube, Elbe, Oder, and Vistula rivers. The discussion for eastern Europe includes the Dnieper, Don, and Volga rivers.

SOILS

Regional divisions. The soil patterns of Europe are clearly and zonally arranged in the East European Plain but are much more complicated in the rest of the continent, which exhibits a more varied geology and relief. Tundra soils occur only in Iceland, the most northerly parts of Russia and Finland, and in high areas of Sweden and Norway; they tend to be acidic, waterlogged, and poor in plant nutrients. South of this zone and extending around the Gulf of Bothnia and across Finland and Russia north of the upper Volga, cool-climate podzols are characteristic. These soils, formed in a coniferous woodland setting, suffer from acidity, the leaching of minerals, hardpan formation and permafrost beneath the topsoil, and excess moisture; given the climate, they are virtually useless for crops.

The larger zone to the south stretches from central Russia westward to Great Britain and Ireland and southward from central Sweden, southern Norway, and Finland to the Pyrenees, Alps, and Balkan Mountains. In this region temperate-climate podzols and brown forest soils have developed in a mixed-forest environment, and these soils, which are highly varied, usually have a good humus content. Locally, the farmer recognizes soils of heavy to light texture, their different water-holding capacities, depth, al-

FPG, Tom Wright



Mountain-encircled Esthwaite Water in the Lake District of northwestern England.

kalinity or acidity, and their suitability for specific crops. The soils, rich in humus, within this zone that cover loess are excellent loams; lowland clays, when broken down, also exhibit high quality, as do alluvial soils; in contrast, areas covered with dry, sandy, or gravelly soils are more useful for residential and amenity purposes than for farming. In southwestern Russia, portions of the Transcaucasus region, and especially in Ukraine, some soils that have been formed in areas of grass steppe are chernozems (black earths)—deep, friable, humus-rich, and renowned for their fertility. In the formerly wooded steppe lying to the north of the grass steppe in both south central Russia and the lower Danubian lowlands, soils of somewhat less value are known as degraded chernozems and gray forest soils. At best, chestnut soils—some needing only water to be productive—and, at worst, solonetzic (highly saline) soils cover areas of increasing aridity eastward of Ukraine to the Ural River. Lastly, in southern Europe, where the countryside is fragmented by mountains, plateaus, and hills, much soil has been lost from sloping ground through forest destruction and erosion, and a bright red soil (terra rossa), heavy and clay-rich, is found in many valleys and depressions.

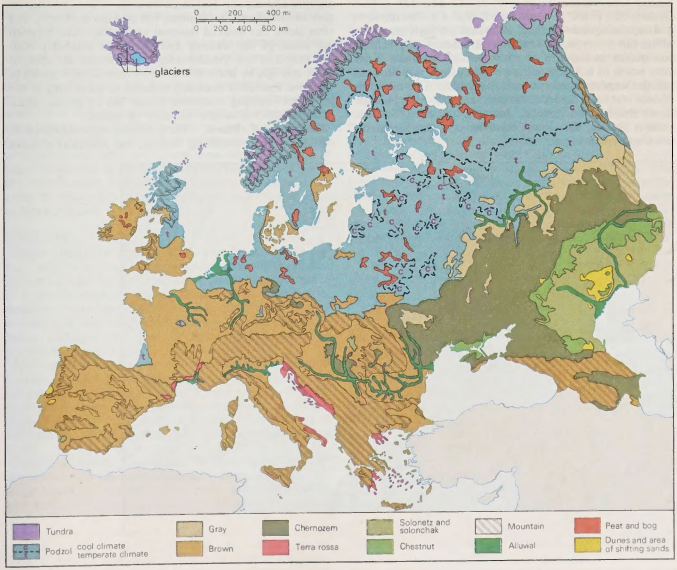
Soil fertility

Problems of classification. The origin, nature, variety, and classification of Europe's soils raise highly complex problems: so much is involved—bedrock, drainage, plant decomposition, biological action, climate, and the time factor. Humans, moreover, have done much to modify soils and, with increasing scientific knowledge, to render soils of greater and continuing value by drainage, crop rotation, and the input of suitable combinations of chemicals. In such ways, naturally poor soils can—as has been shown in Denmark—be made productive. The practice of an enforced "resting" of soils, by leaving fields fallow to recuperate, began to disappear with the agricultural revolution of the 18th century, and agronomic science continues to show how the best results can be achieved from specific soils and also how to check soil erosion. Europe's arable land lies mainly in the lowlands, which have podzols, brown, chernozem, and chestnut soils, although the upper elevation level of cultivation, as of animal husbandry, rises southward. New land is won from the sea, and this more than offsets coastal losses through erosion, but the continued losses to urban expansion and to such competitors for level land as airfields, on the other hand, have become increasingly serious.

CLIMATE

As Francis Bacon, the great English Renaissance man of letters, aptly observed, "Every wind has its weather." It is air-mass circulation that provides the main key to Europe's climate, the more so since masses of Atlantic Ocean origin can pass freely through the lowlands, except in the case of the Caledonian mountains of Norway. Polar air masses derived from areas close to Iceland and tropical masses from the Azores bring, respectively, very different conditions of temperature and humidity and produce different climatic effects as they move eastward. Continental air masses from eastern Europe have equally easy access westward. The almost continuous belt of mountains trending west–east across Europe also impedes the interchange of tropical and polar air masses.

Air-pressure belts. Patterns of some permanence controlling air-mass circulation are created by belts of air pressure over five areas. They are: the Icelandic low, over the North Atlantic; the Azores high, a high-pressure ridge; the (winter) Mediterranean low; the Siberian high, centred over Central Asia in winter but extending westward; and the Asiatic low, a low-pressure, summertime system over southwestern Asia. Given these pressure conditions, westerly winds prevail in northwestern Europe during the year, becoming especially strong in winter. The winter westerlies, often from the southwest, bring in warm tropical air; in summer, by contrast, they veer to the northwest



Soils of Europe.

Westerlies and the Siberian high

and bring in cooler Arctic or subarctic air. In Mediterranean Europe the rain-bearing westerlies chiefly affect the western areas, but only in winter. In winter the eastern Mediterranean basin experiences bitter easterly and northeasterly winds derived from the Siberian high, and their occasional projection westward explains unusually cold winters in western and central Europe, the exceptionally warm winters of which, on the other hand, result from the sustained flow of tropical maritime air masses. In summer the Azores high moves 5°–10° of latitude northward and extends farther eastward, preventing the entry of cyclonic storms into the resultantly dry Mediterranean region. The eastern basin, however, experiences the hot and dry north and northeast summer winds called etesian by the ancient Greeks. In summer, too, the Siberian high gives place to a low-pressure system extending westward, so that westerly air masses can penetrate deeply through the continent, making summer a wet season.

It is because of the interplay of so many different air masses that Europe experiences very changeable weather. Winters get sharply colder eastward, but summer temperatures relate fairly closely to latitude. Northwestern Europe, including Iceland, enjoys some amelioration because of warm Gulf Stream waters, which keep the Russian port of Murmansk open throughout the year.

Climatic regions. Four regional European climatic types can be loosely distinguished, each characterized by much local topographically related variation. Further, the great cities of Europe, because of the scale and grouping of their buildings, their industrial activities, and the layout of their roads, create distinct local climates—including a central "heat island" and pollution problems.

Maritime climate. Characterizing western areas heavily exposed to Atlantic air masses, the maritime type of climate—given the latitudinal stretch of these lands—exhibits sharp temperature ranges. Thus, the January and July annual averages of Reykjavík (Iceland) and Coruña (Spain) are, respectively, 32° F (0° C) and 53° F (12° C), and 50° F (10° C) and 64° F (18° C). Precipitation is always adequate—indeed, abundant on high ground—falling the year round. The greatest amount of precipitation occurs in autumn or early winter. Summers range from warm to hot depending on the latitude and altitude, and the weather is everywhere changeable. The maritime climate extends across Svalbard, Iceland, the Faeroes, Great Britain and Ireland, Norway, southern Sweden, western France, the Low Countries, northern Germany, and northwestern Spain.

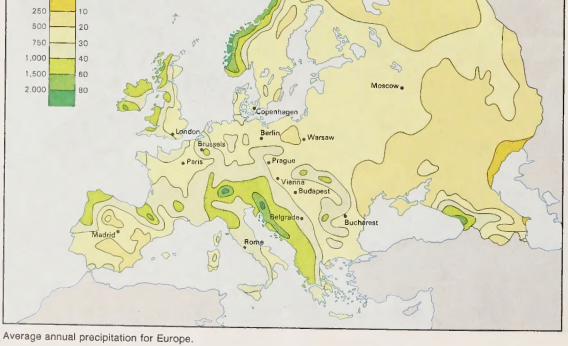
Interaction of air masses

Central European (transitional) climate. The central European, or transitional, type of climate results from the interaction of both maritime and continental air masses and is found at the core of Europe, south and east of the maritime type, west of the much larger continental type, and north of the Mediterranean type. This rugged region has colder winters, with substantial mountain snowfalls, and warmer summers, especially in the lowlands. Precipitation is adequate to abundant, with a summer maximum. The region embraces central Sweden, southern Finland, the Oslo Basin of Norway, eastern France, southwestern Germany, and much of central and southeastern Europe. The range between winter and summer temperatures increases eastward, while the rainfall can exceed 80 inches (2,000 millimetres) in the mountains, with snow often lying permanently around high peaks. The Danubian region has only modest rainfall (24 inches per year at Budapest), but the Dinaric Alps experience heavy cyclonic winter, as well as summer, rain.

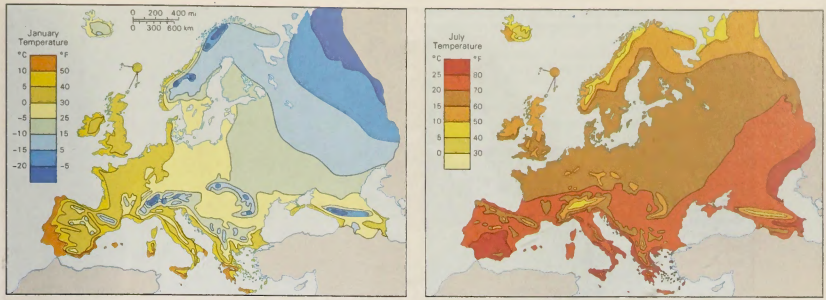
Continental climate. The continental type of climate dominates a giant share of Europe, covering northern Ukraine, eastern Belarus, Russia, most of Finland, and northern Sweden. Winters—much colder and longer, with greater snow cover than in western Europe—are coldest in the northeast, and summers are hottest in the southeast; the January to July mean temperatures range from 50° to 70° F (10° to 21° C). Summer is the period of maximum rain, which is less abundant than in the west: Moscow's annual average is 25 inches, while, in both the north and southeast of the East European Plain, precipitation reaches only between 10 and 20 inches annually. In parts of the south, the unreliability of rainfall combines with its relative scarcity to raise a serious aridity problem.

Mediterranean climate. The subtropical Mediterranean climate characterizes the coastlands of southern Europe, being modified inland (for example in the Meseta Central, the Apennines, and the North Italian Plain) in response to altitude and aspect. The main features of this climatic region are mild and wet winters, hot and dry summers, and clear skies, but marked regional variations occur between the lands of the western and the more southerly eastern basins of the Mediterranean; the former are affected more strongly by maritime-air-mass intrusions. Rainfall in southern Europe is markedly reduced in areas lying in the lee of rain-bearing westerlies: Rome has an annual mean of 26 inches, but Athens has only 16 inches.

The effects of climate. The local and regional effects of climate on the weathering, erosion, and transport of rocks



Average annual precipitation for Europe.



Average temperatures for January (left) and July (right) in Europe.

Adapted from Norton S. Ginsburg (ed.), *Aldine University Atlas* (1970). Aldine Publishing Co., Chicago; copyright © 1970 by George Philip & Son Ltd., London; with permission from the author and Aldine-Atherton, Inc.

clearly contribute much to the European landscape, and the length and warmth of the growing season, the amount and seasonal range of rainfall, and the incidence of frost affect the distribution of vegetation. Wild vegetation in its turn provides different habitats for animal life. Climate is also an important factor in the making of soils, while modern European industry and urban life depend increasingly on water supplies, with rivers and lakes continuing to provide important commercial waterways in some areas. The winter freeze in northern and eastern Europe is another effect of climate, and the spring thaw, by creating floods, impedes transport and harasses farmers. The snow cover of the more continental regions is useful to people, however, for it stores water for the fields and provides snow for sled users.

Regional variations of climate also help determine where crops are grown commercially. In southern Europe the climate supports specially adapted wild vegetation and precludes all-year grass in coastal lowlands, while the practice of moving flocks and herds to pastures seasonally available at different altitudes is clearly adapted to other conditions set by climate. In sum, in only a modest proportion of Europe does climate somewhat restrict human occupation and land use. These areas include regions of high altitude and relief, such as the subarctic highlands of the Scandinavian Peninsula and Iceland, the Arctic areas along the White Sea of northern Russia, and the arid areas of interior Spain.

PLANT LIFE

Major vegetation zones. The terms "natural," "original," and "primitive," as epithets applied to the vegetation of Europe, have no precise meaning unless they are related to a specific time in geologic history. It is, nevertheless, possible to envisage continental vegetation zones as they formed and acquired some stability during postglacial times, although such zones are only rarely recalled by present-day remnants.

The tundra. Tundra vegetation, made up of lichens and mosses, occupies a relatively narrow zone in Iceland and the extreme northern portions of Russia and Scandinavia, although this zone is continued southward in the mountains of Norway. Vegetation of a similar kind occurs at altitudes of 5,000–6,000 feet in the Alps and the northern Urals.

The boreal forest. Southward, the virtually treeless tundra merges into the boreal (northern) forest, or taiga. The more northerly zone is "open," with stands of conifers and with willows and birch thickets rising above a lichen carpet. It is most extensive in northern Russia but continues, narrowing westward, across Sweden. South of this zone, and with no abrupt transition, the "closed" boreal forest occupies a large fraction—mainly north of the upper Volga River—of Russia and Scandinavia. Conifers, thin-leaved and resistant to cold, together with the birch and larch, predominate.

The mixed forest. The northern vegetation may superficially suggest its primeval character, but the zone of mixed forest that once stretched across the continent from Great Britain and Ireland to central Russia has been changed extensively by humans. Only surviving patches of woodland—associations of summer-leaf trees and some conifers, summarily described as Atlantic, central, and eastern—hint at the formerly extensive cover.

The Mediterranean complex. In southern Europe, Mediterranean vegetation has a distinctive character, containing hard-leaf forests and secondary areas of scrub, especially maquis (macchie), which is made up of trees, shrubs, and aromatic plants. Such scrub is scattered because of summer drought, particularly in areas where the soil is underlain by limestone or where there is little, if any, soil.

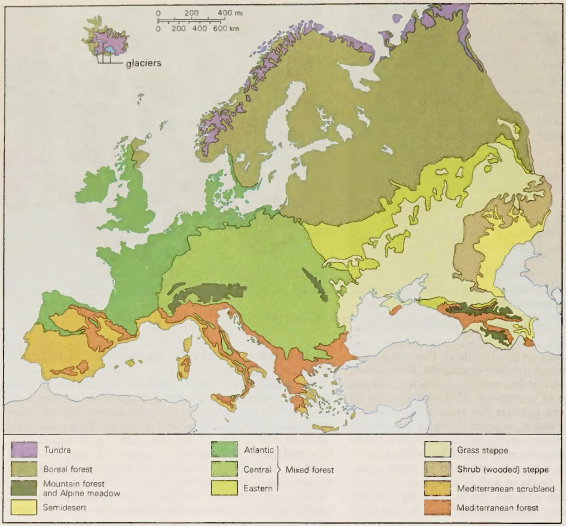
Steppe and semidesert. The wooded-steppe and grass-steppe vegetation zones are confined primarily to southwestern Russia and Ukraine, although they also extend into the Danubian lowlands. Finally, semidesert vegetation characterizes the dry lowland around the northern and northwestern shores of the Caspian Sea.

The shaping of vegetation zones. *Climatic change.* The primeval vegetation of Europe began to take shape as the climate ameliorated following the retreat of the Pleistocene ice sheets. The microscopic study of pollen grains preserved in datable layers of peat and sediments has made it possible to trace the continental spread, in response to

H. Fristedt—Carl E. Ostman ab



Coniferous forests and lakes on the ancient Baltic Shield of Finland.



Vegetation zones of Europe.

The Alpine Barrier

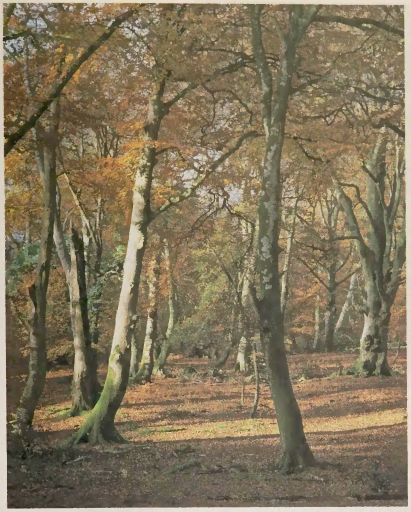
climatic improvement, of forest-forming trees. The double barrier of the Alps and the Mediterranean Sea had checked the retreat of trees at the onset of the Great Ice Age, and there were relatively few indigenous species to return northward from unglaciated refuges. In the first postglacial climatic phase (the Boreal), spruce, fir, pine, birch, and hazel nevertheless established themselves as far north as central Sweden and Finland. During the succeeding climatic optimum (the Atlantic phase), which was probably wetter and certainly somewhat warmer, mixed forests of oak, elm, common lime (linden), and elder spread northward. Only in the late Atlantic period did the beech and hornbeam spread into western and central Europe from the southeast.

During postglacial times, therefore, when small numbers of humans were living within Europe, the continental surface was thickly clad with trees and undergrowth, except where tree growth was precluded by extreme cold, high altitude, bad drainage, or exposure to persistent gales. Even those relatively attractive areas where windblown loess had been deeply deposited are now known to have had woods of beech, hawthorn, juniper, box, and ash, as did also limestone plateaus. The Mediterranean peninsulas also had evergreen and mixed forests rooted in an ample soil.

The role of humans. From prehistoric times onward, with ever-increasing force, humans, seeking optimum economic use of available resources, have acted as a vigorous agent of vegetation change. The effects of grazing animals may well explain why some heathlands (*e.g.*, the Lüneburg Heath in north central Germany) replaced primeval forest. By fire and later by ax, forest clearance met demands for homes and ships, for fuel, for charcoal for iron smelting, and, not least, for more cultivation and pasture. The mixed boreal forests suffered most because their relatively rich soils and long and warm growing season promised good returns from cultivation. The destruction of woodlands was markedly strong when population was growing (as between about AD 800 and 1300). It was later intensified by German colonization east of the Rhine and reached maximum scale in the 19th century. In southern Europe—where naval demands were continuous and sources of suitable timber sharply localized—tree cutting entailed, from classical antiquity onward, serious soil loss through erosion, increased aridity, floods, and marsh formation. Farther north throughout the continent, as present distribution of arable land shows, former forests were reduced to remnants; only in the north and below the snow line of Alpine mountains have forests of large and continuing commercial value survived. These coniferous forests of Sweden, Finland, and northern Russia are "cropped" annually to preserve their capital value. On the more positive side may be noted the reclamation of marshlands and the soil improvement of hill grasslands and heaths, their wild vegetation being replaced by pasture and crops; in timber-deficient countries the afforestation of hillslopes, chiefly with quickly growing conifers, belatedly attempts to restore some of the former forests. Another drastic vegetation change brought about by humans has been the virtual elimination of the wooded and grass steppes, which have become vast granaries.

Afforestation in Scandinavia and Russia

Exterior influences and European survivals. To a surprising degree, European vegetation stemmed from the importation of plants from other continents, although some imported crops—notably citrus fruits, sugarcane, and rice—can grow only marginally in Europe, and then by irrigation. From an original home of wild grasses in Ethiopia, cultivated varieties of wheat and barley reached Europe early, via the Middle East and Egypt, as did also the olive, the vine, figs, flax, and some varieties of vegetables. Rice, sugarcane, and cotton, of tropical Indian origin, were introduced by the Arabs and Moors, especially into Spain. The citrus fruits, peaches, mulberries, oats, and millet reached Europe from original Chinese habitats, and Europe owes corn (maize), tobacco, squashes, tomatoes, red peppers, prickly pears, agave (sisal), and the potato—first grown for fodder but destined to become the cheap staple food for the large families of low-paid workers of the 19th century—to the Americas. Europe has drawn greatly



Deciduous forest of beech in autumn, New Forest, southern England, U.K.
Heather Angel—Biofotos

on East Asia and North America for trees, especially ornamental trees, while some acacias and the eucalyptus derive from Australia. The sugar beet, however, was a European discovery, first grown when much of Napoleonic Europe was subjected to maritime blockade.

The forests of northern Europe and the Alpine ranges, although in no sense primeval, represent unchanging land use during the postglacial period. The "closed boreal forest" occupies some one million square miles (2.6 million square kilometres), made up of a spruce–fir association (but with stands of pine, birch, and larch) above an undergrowth of mosses and herbs. This large and valuable reserve of timber is of world importance; forests once covered 80 percent of Europe's surface, and they still occupy about 30 percent.

Human adaptations. Clearly, animal life, wild and domesticated, has been adjusted to fit largely man-made patterns of vegetation, which, in turn, reflect agelong attempts to achieve chiefly economic ends. With such endeavours are associated varieties of *modes de vie*, or "modes of livelihood." In the mountains as in the boreal forests, the environment is exploited by winter lumbering and by the transport of felled trees by river after the spring thaw. So, too, agriculture in its many forms—in part for subsistence but commonly for urban markets—is a basic occupation of the lowlands, long cleared of extensive forests or steppe vegetation. In Mediterranean Europe, rural life, based on horticulture and arboriculture rather than on large-scale cultivation, as well as on the rearing of sheep and goats and wheat cultivation, continues, little changed in many areas. For such deeply rooted fruit-bearing trees as the olive and vine, use is made of sloping, broken, and terraced land. Farming also extends to specialized forms with respect to the subtropical crops that climate, sometimes supplemented by irrigation, permits.

Modes de vie

ANIMAL LIFE

Patterns of distribution. With animals as with plants, the earlier Pleistocene range and variety has been much reduced since man disposed of what nature provided. Wild fauna has been long in retreat since Upper Paleolithic times, when, as cave drawings portray, small human groups held their own against such big game as aurochs and mammoths, now extinct, and also against such survivors as the elephant, bison, horse, and boar. Hares, swans, and geese were also hunted, and salmon, trout, and pike were fished. Humans were, inevitably, the successful competitor for land use. By prolonged effort settlers won the land for crops and for domesticated animals, and they hunted animals, especially for furs. As population mounted in industrializing Europe, humans no less inevitably destroyed, or changed drastically, the wild vegetation cover and the animal life. With difficulty, and largely on human sufferance, animals have nevertheless survived in association with contemporary vegetation zones.

The tundra. In the tundra some reindeer (caribou), both wild and domesticated, are well equipped to withstand the cold. Their spoon-shaped hooves are useful in finding food in rough ground. Their herds migrate southward in winter and eat lichens and other plants, as well as flesh, notably that of lemmings and voles. Dogs, too, are reared for traction but yield less than reindeer, which also provide meat, milk, pelts, wool, and bone. The Arctic fox, bear, ermine, partridge, and snowy owl may appear in the

Oleg Polunin



Maquis (macchie) vegetation on the Mediterranean coast, near Sithonia, Greece.



Steppe grasslands at Point Kaliakra, Bulg., on the northwestern shore of the Black Sea.
Oleg Polunin

tundra, where, in the short summer, seabirds, river fish, and immigrant birds (swans, ducks, and snipes) vitalize a harsh environment then made almost intolerable by the swarms of biting midges.

The thinning out of animal species in boreal forests

Boreal associations. In the boreal forests the richness of animal and bird life, which had persisted throughout historical times, now has been greatly reduced. Among large surviving ungulates are the elk (moose), reindeer, and roebuck, and among big beasts of prey is the large brown bear. The lynx has been exterminated by humans, but not the wolf, fox, marten, badger, polecat, and white weasel. The sable, which is much hunted for its valuable fur, only just survives in the northeastern forests of European Russia. Rodents in the forests include squirrels, the white Arctic hare, and (in the mixed forests) the gray hare and the beaver. Among birds are the black grouse, snipe, hazel hen, white partridge, woodpecker, and crossbill, all of which assume protective colouring and are specially adapted to be able to find their food in a woodland environment. Owls, blackbirds, tomtits, and bullfinches may be seen in the forests, and, in meadow areas, geese, ducks, and lapwings may be seen.

The steppes. The fauna of the steppe zones now lacks large animals, and the saiga antelope has disappeared. Numerous rodents, including the marmot, jerboa, hamster, and field mouse, have increased in numbers to become pests, now that nearly all the steppe is under cultivation. Equally plentiful birds include the bustard—who can fly as well as run—quail, gray partridge, and lark. These take on yellowish gray or brown protective colouring to match the dried-up grass. Eagles, falcons, hawks, and kites comprise the birds of prey; water and marsh birds—especially the crane, bittern, and heron—also make their homes in the steppes. Different kinds of grasshopper (locusts) and beetles are insect pests.

Mediterranean and semidesert associations. In Mediterranean Europe, remnants of mountain woodland harbour wild goats, wild sheep—such as the small mouflon of Corsica and Sardinia—wildcats, and wild boar. Snakes, including vipers, and lizards and turtles are familiar reptiles, but birds are few. The faunas of the semidesert areas to the north and northwest of the Caspian Sea also show affiliations with the grass steppe and the desert between which they lie. Two types of antelope (saiga and jaran) survive there, as do rodent sand marmots and desert jerboas and, as a beast of prey, the sand badger. There are many reptiles—lizards, snakes (cobras and steppe boas)—and tortoises. The Pander's ground jay and the saxaul sparrow, the latter named for the desert tree, also live there, while scorpions, the karakurt spiders, and the palangid are insects dangerous to humans and camels.

Conservation problems. Pressure on space, hunting, either for sport or to protect crops, the pollution of sea waters and fresh waters, and the contamination of cropland have so reduced many animal species that strong efforts are now being made to preserve those threatened with extinction, in such refuges where they still, precariously, live.

Nature reserves

Nature reserves have been set up in many European countries, with international support from the International Union for Conservation of Nature and Natural Resources and the World Wildlife Fund. Seabirds find safe homes, for example, in the Lofoten Islands of Norway and the Farne Islands of northeastern England. The snowy owl, which feeds on lemmings, is seen in Lapland, the rare great bustard in the Austrian Burgenland, and the muskox in Svalbard. Père David's deer, which had become extinct in China, its native home, was introduced in 1898 at Woburn Abbey, Eng., where it now flourishes. Nearly half the bird species of Europe, including the egret and the imperial eagle, are represented in the Doñana National Park, within a setting of wild vegetation in the Las Marismas region of the Guadalquivir estuary in southwestern Spain; there, too, the Spanish lynx survives. In Poland the extensive Białowieża National Park, a wild forest once hunted yearly by the tsars, contains deer, wild boar, elk (moose), bear, lynx, wolves, eagle owls, black storks, the European bison (wisent), and the tarpan, a gray-coloured horse and a survivor from remote days. Contiguous with the forest in Belarus is the Belavezhs Forest Preserve, containing European bison. Italy has its reknowned Gran Paradiso National Park in the Valle d'Aosta, which preserved from extinction the Alpine ibex; Austria has a bird refuge in Neusiedler Lake (Lake Fertő), which is the only breeding site of white egrets in western Europe; and the huge delta of the Danube is largely left to wildlife. The golden eagle, Alpine marmots, and chamois are to be seen in the Bavarian Alps near Berchtesgaden, Ger.

Other rare birds are the sandwich tern, at Norderoog Island in the North Frisian Islands of Germany, and the spoonbill and cormorant, found, respectively, at Texel Island and Norderoog Island, the former off the coast of The Netherlands. For ornithologists (as for botanists) Iceland has abounding interest, notably at Slúttnes, an island in the shallow Lake Mývatn. The beautiful wild horses of Camargue Nature Reserve (Rhône delta), the wild ponies of the New Forest (England), and the Barbary apes, maintaining a foothold on the Rock of Gibraltar, continue undiminished in popular interest.

Thus, the European environment, once not so unequally shared by plants, animals, and people, has, with the march of civilization, been subjected to the attempt at mastery by humans. Favoured by their proximity to the Middle East, where crop cultivation and animal domestication first began, Europeans have fashioned cultural landscapes at the expense of wild nature to serve their economic and social ends. Only with difficulty—and sporadically—has wild nature survived, and only just in time has awareness of the cultural losses from the impoverishment of natural vegetation and its animal associates underlined the urgent need for careful protection and preservation of nonhuman nature for communal enjoyment and scientific research.

Against certain pests, notably the anopheles mosquito and the rabbit, war has been waged with good effect, for malaria no longer afflicts Mediterranean Europe, and rabbits, competitors for grass, have been greatly reduced. On the credit side, too, should be listed the full use made of domesticated animals for pastoral husbandry—on high and rough ground, as well as on farms. The familiar farm animals are selectively bred and raised with some regard to the physical character of their environment as well as to market demands and government decisions. In the far north, herds of reindeer are adapted to withstand cold and to find their food in snow-covered ground. In the rough hilly scrubland of Mediterranean Europe, the sheep, goat, donkey, mule, and ass have adapted well. The horse, which in its long history has drawn chariots, carried mounted knights, and hauled the plow, wagons, artillery, stagecoaches, canalboats, and urban trams, is now largely replaced as a draft animal by the tractor, truck, and jeep. Now chiefly raised for racing, riding, ceremonials, and the hunting of fox and stag, the horse is still used for farm work, especially in eastern Europe. Distribution maps of animals kept on farms show how widely they enter into farming: sheep have a special concentration in Great Britain and the Balkan countries, and cattle have a small place in southern Europe, while pigs are relatively numerous in the north, especially in the highly populated areas of Germany, Denmark, and the Low Countries.

Farm animals

The people

The great majority of Europe's inhabitants have lightly pigmented skins, but an increasing number of people are of African and Asian ancestry. The origins of the Europeans as a distinct group may never be learned. It is known, however, that the continent had a scanty population of now-extinct hominid species before modern humans appeared some 40,000 years ago and that throughout its prehistoric period it received continual waves of immigrants from Asia. The legacy of these immigrants can be seen in the large spectrum of physical types and cultural features that are found throughout Europe.

CULTURAL PATTERNS

Culture groups. Efforts have been made to characterize different "ethnic types" among European peoples, but these are merely selectively defined physical traits that, at best, have only a limited descriptive and statistical value. On the other hand, territorial differences in language and culture are well known; these have been of immense social and political import in Europe.

These differences place Europe in sharp contrast to such relatively recently colonized lands as the United States, Canada, and Australia. Given the agelong occupation of its soil and minimal mobility for the peasantry—long the bulk of the population—Europe became the home of many linguistic and national "core areas," separated by mountains, forests, and marshlands. Its many states, some long-established, introduced another divisive element that was augmented by modern nationalistic sentiments. Efforts to associate groups of states for specific defense and trade functions, especially after World War II, created wider unitary associations, with fundamental East–West differences. Thus, there appeared two clear-cut, opposing units—one centred around the Soviet Union and the other around the countries of western Europe—and a number of relatively neutral states (Ireland, Sweden, Austria, Switzerland, Finland, and Yugoslavia). This pattern subsequently was altered in the late 1980s and early 1990s with the dissolution of the Soviet bloc (including the Soviet Union itself), the rapprochement between East and West, and the expansion of the European Union.

The map showing the distribution of European ethnic culture areas identifies some 160 different groups, including a number of groups in the Caucasus region that have affinities with both Asia and Europe. Each of these large groups exhibits two significant features. First, each is characterized by a degree of self-recognition by its members, although the basis for such collective identity varies from group to group. Second, each group—except the Jews and Roma (Gypsies)—tends to be concentrated and numerically dominant within a distinctive territorial homeland.

Ethnographic culture area

For a majority of groups the basis for collective identity is possession of a distinctive language or dialect. The Basques, Catalans, and Galicians of Spain, for example, have languages notably different from the Castilian of the majority of Spaniards. On the other hand, some peoples may share a common language yet set each other apart because of differences in religion. In the Balkan region, for instance, the Eastern Orthodox Serbs, Muslim Bosniacs, and Roman Catholic Croats all speak a language that linguists refer to as the Serbo-Croatian language; the members of each group generally have antagonistic views toward the others, and each prefers to designate the common language as Serbian, Bosnian, or Croatian. Some groups may share a common language but remain separate from each other because of differing historic paths. Thus, the Walloons of southern Belgium and the Jurassians of Switzerland both speak French, yet they see themselves as quite different from the French because their groups have developed almost completely outside the boundaries of France. Even when coexisting within the same state, some groups may have similar languages and common religions but remain distinctive from each other because of separate past associations. During the 75 years that the Czechs and Slovaks were citizens of a single state, Czechoslovakia, the historic linkages of Slovaks with the Hungarian kingdom and Czechs with the Austrian state kept the two groups apart; the country was divided into two separate states, the Czech Republic and Slovakia, in 1993.

The primary European groups represented on the map have been associated by ethnographers into some 21 culture areas. The grouping is based primarily on similarities of language and territorial proximity. Although individuals within a primary group generally are aware of their cultural bonds, the various groups within an ethnographic culture area do not necessarily share any self-recognition of their affinities to one another. This is particularly true in the Balkan culture area. Peoples in the Scandinavian and German culture areas, by contrast, are much more aware of belonging to broader regional civilizations.

Languages. *Romance, Germanic, and Slavic languages.* Within the complex of European languages, three major divisions stand out: Romance, Germanic, and Slavic. All three are derived from a parent Indo-European language of the early migrants to Europe from southwestern Asia.

The Romance languages dominate western and Mediterranean Europe and include French, Spanish, Portuguese, Italian, and Romanian, plus such lesser-known languages as Occitan (Provençal) in southern France, Catalan in northeastern Spain and Andorra, and Romansh in southern Switzerland. All are derived from the Latin language of the Roman Empire.

The Germanic languages are found in central, northern, and northwestern Europe. They are derived from a common tribal language that originated in southern Scandinavia, and they include German, Netherlandic, Danish, Norwegian, Swedish, and Icelandic, as well as the minor Germanic tongue of Frisian in the northern Netherlands and northwestern Germany; Netherlandic often is referred to as being "Dutch" in The Netherlands and "Flemish" in northern Belgium and adjacent parts of northern France, but in actuality it is only one language. English is a Romance-Germanic hybrid.

The Slavic languages are characteristic of eastern and southeastern Europe and of Russia. These languages are



PRIMARY EUROPEAN ETHNIC CULTURE AREAS

I. The Atlantic fringe

Celtic culture area
1. Gaelic-speaking Irish
2. English-speaking Irish
3. Manx
4. Gaelic-speaking Scottish
5. English-speaking Scottish
6. Celtic-speaking Welsh
7. English-speaking Welsh
8. Cornish
9. Celtic-speaking Bretons
10. French-speaking Bretons

English culture area
11. English

French culture area
12. French
13. Walloons
14. Jurassian Swiss
15. French-Swiss
16. Valdotains

Netherlandish culture area
17. Dutch
18. Flemings
19. Frisians

Scandinavian culture area
20. Danes
21. Faroese
22. Icelanders
23. Norwegians
24. Swedes
25. Finnish Swedes

II. The Mediterranean

Iberian culture area
26. Spaniards
27. Galicians
28. Portuguese

Pyrenean culture area
29. Basques
30. North Aragonese
31. Catalans
32. Béarnese
33. Bigorgans
34. Gascons
35. Lower Languedocians

Mediterranean-Alpine culture area
36. Provençals
37. Savoyards
38. Piedmontese

Italic culture area
39. Rhaeto-Romansh
40. Ladins
41. Friulians
42. North Italians
43. Middle Italians
44. South Italians
45. Sicilians
46. Corsicans
47. Sardinians
48. Maltese

Balkan culture area
49. Cypriots
50. Greeks
51. Albanians
52. Macedonians
53. Bulgarians
54. Romanians
55. Aromuns
56. Serbs
57. Montenegrins
58. Hercegovinians
59. Bosnians
60. Dalmatians
61. Croats
62. Chich
63. Slovenes

III. The Carpatho-Alpine–West Plain climax

German culture area
64. West Lower Germans
65. East Lower Germans*
66. Middle Germans
67. Upper Germans
68. Alemanni
69. Bavarians
70. Transdanubian Swabians
71. Transylvanian Saxons
72. Moldavian Germans*
73. Volga Germans*

Baltic culture area
74. Lithuanians
75. Latvians

West Slavic culture area
76. Sorbs (Wends)
77. Kashubians
78. Slovincz
79. Poles
80. Mazurians
81. Gorale
82. Czechs
83. Horaks
84. Zahorcks
85. Hannaks
86. Slovaks

West Ugric culture area
87. Hungarians (Magyars)
88. Siculi
89. Csangos

IV. The East Plain and the Caucasus

West Finno-Permian culture area
90. Finns
91. Karelians
92. Saami (Lappo)
93. Ingrians
94. Veps
95. Votes
96. Estonians
97. Livonians

Samoyed culture area
98. Nenets

East Finno-Permian culture area
99. Mordvins
100. Maris (Cheremis)
101. Udmurts (Votyaks)
102. Komis

East Slavic culture area
103. Belarusian
104. Ukrainians
105. Volhynians
106. Podolians
107. Lemks
108. Boyks
109. Ruthenians
110. Hutsuls
111. Lipovans
112. North Great Russians
113. South Great Russians
114. Pomors

Pre-Uralian Turko-Tatar culture area
115. Chuvash
116. Kazan Tatars
117. Tepteris
118. Bashkirs
119. Misars

Ponto-Caspian Turko-Tatar culture area
120. Crimean Tatars*
121. Karachays*
122. Teuli
123. Kumyks
124. Nogays
125. Turkmens
126. West Kazakh-Kirgiz
127. Lower Volga Tatars

Caucasian culture area
128. Circassians
129. Balkars*
130. Abkhaz
131. Mingrelians
132. Gurians
133. Laz
134. Georgians
135. Ymar
136. Svan
137. Ossetes
138. Ingush
139. Pshav
140. Mtiul
141. Khevsur
142. Thush
143. Lezgians
144. Kabardians
145. Chechens (Shishans)*
146. Avars
147. Dido
148. Andi
149. Lekks
150. Tabasarans
151. Dargins
152. Kyrinans
153. Tats

Sporadic ethnic units of extra-European origins
154. Kalmyks
155. Azerbaijanian Tatars
156. Armenians
157. Kurds
158. Romano-Turks
Roma (Gypsies)
Jews

*Peoples partly dispersed by the Soviet government since 1944 (Volga Germans since 1941), but preserving the right to their native homes.

Distribution of European ethnic culture areas.

Three branches

usually divided into three branches: West, East, and South. Among the West Slavic languages are Polish, Czech and Slovak, Upper and Lower Sorbian of eastern Germany, and the Kashubian language of northern Poland. The East Slavic languages are Russian, Ukrainian, and Belarusian. The South Slavic languages include Slovene, Serbo-Croatian, Macedonian, and Bulgarian.

Other languages. In addition to the three major divisions of the Indo-European languages, three minor groups are also noteworthy. Modern Greek is the mother tongue of Greece and of the Greeks in Cyprus, as well as the people of other eastern Mediterranean islands. Older forms of the language were once widespread along the eastern and southern shores of the Mediterranean and in southern peninsular Italy and Sicily. The Baltic language family includes modern Latvian and Lithuanian. The Old Prussian language also belonged to the Baltic group but was supplanted by German through conquest and immigration. Europe's Gypsies speak the distinctive Romany language, which has its origins in the Indic branch of the Indo-European languages.

Two other Indo-European language divisions were formerly widespread but now are spoken only by a few groups. Celtic languages at one time dominated central and western Europe from a core in the German Rhineland. Cultural pressures from adjacent Germanic- and Romance-speaking civilizations eliminated the Celtic culture area, save for a few remnants, including the Welsh, the Gaelic speakers of the Scottish Highlands and western Ireland, and the Celtic-speaking Bretons of the northwestern Brittany peninsula of France. The Thraco-Illyrian branch of the Indo-European languages formerly was spoken throughout the Balkan Peninsula north of Greece. It survives solely in the Albanian language.

Non-Indo-European languages also are spoken on the continent. The sole example in western Europe is the Basque language of the western Pyrenees Mountains; its origins are obscure. In northeastern Europe the Finnish, Sami, Estonian, and Hungarian languages belong to the Uralic language family, which has other representatives in the middle Volga River region. Turkic languages are spoken in portions of the Balkan and Caucasus regions.

Religions. The majority of primary culture groups in Europe have a single dominant religion, although the English, German, and Hungarian groups are noteworthy for the coexistence of Roman Catholicism and Protestantism. Like its languages, Europe's religious divisions fall into three broad variants of a common ancestor, plus distinctive faiths adhered to by smaller groups.

Christianity. Most Europeans adhere to one of three broad divisions of Christianity: Roman Catholicism in the west and southwest, Protestantism in the north, and Eastern Orthodoxy in the east and southeast. The divisions of Christianity are the result of historic schisms that followed its period of unity as the adopted state religion in the late stages of the Roman Empire. The first major religious split began in the 4th century, when pressure from "barbarian" tribes led to the division of the empire into western and eastern parts. The bishop of Rome became spiritual leader of the West, while the patriarch of Constantinople led the faith in the East; the final break occurred in 1054. The line adopted to divide the two parts of the empire remains very much a cultural discontinuity in the Balkan Peninsula today, separating Roman Catholic Croats, Slovenes, and Hungarians from Eastern Orthodox Montenegrins, Serbs, Bulgarians, and Romanians. The second schism occurred in the 16th century within the western branch of the religion, when Martin Luther inaugurated the Protestant Reformation. Although rebellion took place in many parts of western Europe against the central church authority vested in Rome, it was successful mainly in the Germanic-speaking areas of Britain, northern Germany, the Netherlands, and Scandinavia, the latter including the adjacent regions of Finland, Estonia, and Latvia.

East-West break

Judaism and Islām. Judaism has been practiced in Europe since Roman times. Jews undertook continued migrations into and throughout Europe, in the process dividing into two distinct branches, the Ashkenazi and Sephardi. Although through persecution and emigration their numbers are much reduced in Europe—particularly in eastern Europe, where Jews once made up a large minority population—Jews are still found in urban areas throughout the continent.

Islām also has a long history in Europe. Islāmic incursions into the Iberian and Balkan peninsulas have been influential in the cultures of those regions. Muslim communities still exist in several parts of the Balkans, including European Turkey, Albania, Bosnia and Herzegovina, and northeastern Bulgaria. Muslims are more numerous in European Russia, including the Kazan Tatars and Bashkirs in the Volga-Ural region, and in the Caucasus region, including the Azerbaijani and other groups.

DEMOGRAPHIC PATTERNS

Europe has always been one of the most populous parts of the world. Although its estimated population numbered only one-third of Asia's in 1650, 1700, and 1800, this nevertheless accounted for one-fifth of humanity. Despite large-scale emigration, this proportion increased to one-fourth by 1900. Such high numbers, achieved by high birth rates and falling death rates, were sustained by expanding economies. As numbers have grown proportionately faster in the Americas, Asia, and Africa, Europe's population has fallen to about one-eighth of the world total.

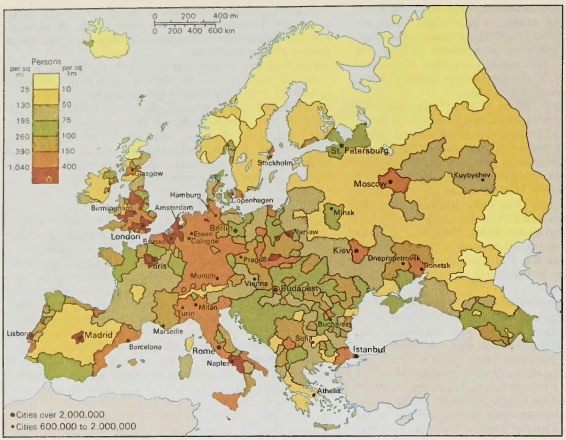
Overall densities. In antiquity the focus of settlement was in southern Europe; but the south lost its numerical domination as, from medieval times onward, settlement developed vigorously in western and central Europe and as, later still, the steppelands of Ukraine and Hungary were settled for crop farming. While northern Europe, from Iceland and the Scottish Highlands to northern Russia, is only scantily settled, the population reaches high densities in a more southerly belt, stretching from England across northern France and industrial Germany to the Moscow region.

A second major population strip extends southward from the Ruhr valley in Germany through Italy. High populations are often associated with coalfields that, in the past more than today, strongly attracted industry, although giant cities like London, Paris, and St. Petersburg, offering large markets and labour forces, have created regions of high density. Other populous areas are sustained by mining, industry, commerce, and productive agriculture. The Netherlands is the most densely populated country; Iceland and Norway are the least dense. Population is scantiest in mountain regions, some highlands, arid parts of Spain, and the Arctic regions of Russia.

High-density areas

Urban and rural settlement. With easier travel and the lure of developing industrial areas, many culturally rich, high-altitude areas have suffered severe depopulation. Urbanization—offering varied employment, better social services, and, apparently, a fuller life—has further reduced the rural population, a drift aided by the mechanization of agriculture. City life has, from classical antiquity, nurtured European culture, although tributary rural life was for centuries the common lot. During the 19th and 20th centuries, however, there has been a revolutionary urbanization that embraces the majority of contemporary Europeans. Some towns are old, containing architectural survivals from their historic past; many more are creatures of the Industrial Revolution.

The great majority of Europeans—more than three in five—now live in cities. In most of the highly industrialized countries the proportion of urban dwellers is high: more than 90 percent in Belgium, The Netherlands, and Iceland and almost 90 percent in Malta, Luxembourg, San Marino, and the United Kingdom. In Germany, Denmark, and Sweden more than 80 percent of the population is urban, and in Estonia, France, Greece, Norway, and Spain the figure is greater than 70 percent. Only the countries of Albania, Bosnia and Herzegovina, Moldova, Slovenia, and Portugal have urban populations that number less than half of their national totals. Towns of different scale and varying function continue to grow rapidly, usually in concentric rings outward from the original core. Europe contains a significant number of the world's cities with a population of more than one million, and many of the more highly industrialized parts of the continent



Population density of Europe.

are marked by giant, sprawling metropolitan areas. One distinct type is represented by the conurbation resulting from outgrowth from London; another, as in the Ruhr, by fusing together separate cities. Both types stem from an unchecked industrial expansion associated with population growth—including immigration from rural areas. As elsewhere in the world, these giant agglomerations pose difficult social and aesthetic problems, but by concentrating population they help to prevent the countryside from becoming too built-up.

Population trends. Western and northern Europe took the lead in the medical and social "death controls" that since the mid-19th century have sharply reduced infant mortality and lengthened life expectancy. Although infant mortality rates have remained relatively high in the countries of eastern Europe, low mortality rates have been achieved virtually everywhere else on the continent.

Birth rates and death rates, as they vary in time and place, necessarily affect the proportion of the population available to the different European countries for the economy and the armed forces. In most countries, increased longevity and lowered birth rates have generated a rising proportion of retired citizens. Also, the trend toward education over longer periods has drawn more young people from the economy. The labour force thus has been shrinking somewhat, although everywhere (except in Spain, Malta, Ireland, and Greece) it has continued to constitute more than two-fifths of the population, exceeding half the population in most countries. Labour-force totals have remained high on the continent primarily because of the increasing proportion of employed women.

The labour force

Emigration and immigration. Despite heavy mortality resulting from continual wars, Europe always has been in modern times a generous source of emigrants. Since the geographic discoveries of the late 15th century, both "push" and "pull" factors explain an exodus greatly accelerated by modern transportation. The push factors often were sheer poverty, the desire to escape from persecution, or loss of jobs through economic change. The pull factors included new opportunities for better living, often at the expense of original inhabitants elsewhere. All of Europe shared in this huge transfer of population, which affected the settlement and economic development of the Americas, Australia, southern Africa, and New Zealand. Through their involvement in the horrors of the African slave trade, Europeans also produced forced migrations of nonwhite peoples that were to have immense consequences in the Old and New Worlds. Since the early 19th century an estimated 60 million people left Europe for overseas; more than half settled in the United States. Ireland lost much of its population following the potato famine of the 1840s. Northwestern Europe—Great Britain, Scandinavia, and the Low Countries—contributed the largest share of emigrants, who settled, above all, where English was spoken. Emigrants from central, eastern, and southern Europe moved later, many in the early decades of the 20th century. Affinities of languages, religion, and culture clearly explain migration patterns; South American countries, for example, had more appeal to Spanish, Portuguese, and Italians. It has been estimated that emigration from 1846 to 1932 reduced the growth rate of Europe's population by three per 1,000 per annum. The year 1913 marked a peak, with at least 1.5 million—one-third Italian and more than a quarter British—migrating overseas. Subsequent entry restrictions in the United States reduced this flood. During the late 20th century, European migrants sought new homes mainly in Australia, Canada, South America, Turkey, and the United States.

Despite high population densities, some European countries still attract settlers from other continents, mainly because their expanding economies involve labour shortages. Thus France, to increase a labour force depleted by war losses and low 1930s birth rates, has received numerous French-Algerians (as well as other Europeans, including Turks) to supplement its labour force. The United Kingdom, which steadily supplies immigrants to Australia and Canada and specialist workers to the United States, has also attracted immigrants, notably Commonwealth citizens. These immigrants, who largely work in the construction industries, transport, hospitals, and domestic service, include also doctors, scholars, and businesspeople. Some, having established themselves, are able to provide homes for their immigrant relatives. There also has been a significant migration of Slavs to the Asian portion of Russia and to the Central Asian republics.

Within the continent there always has been some mobility of population, high during prehistoric times and well marked during the period of decline and fall of the Roman Empire in the West, when many tribal groups—especially of Germans and Slavs—settled in specific regions where they grew into distinctive nations. During and after World War II many Germans from outlying settlements

Intra-continental migrations

in central and east-central Europe returned to western Germany, some as forced migrants. Many eastern Europeans, too, made their way to the West until the sealing of the East–West border curtailed this flow. Migrants are chiefly workers seeking temporary work and, often with less success, new homes. The countries of the European Union (EU) draw workers from southern Europe, as does Switzerland. Two other conspicuous forms of mobility in Europe are the daily commuting of city workers and the increasing movements of tourists. (W.G.E./T.M.P.)

The economy

Europe was the first of the major world regions to develop a modern economy based on commercial agriculture and industrial development. Its successful modernization can be traced to the continent's rich endowment of economic resources, its history of innovations, the evolution of a skilled and educated labour force, and the interconnectedness of all its parts—both naturally existing and man-made—which facilitated the easy movement of massive quantities of raw materials and finished goods and the communication of ideas.

Europe's economic modernization began with a marked improvement in agricultural output in the 17th century, particularly in England. The traditional method of cultivation involved periodically allowing land to remain fallow; this gave way to continuous cropping on fields that were fertilized with manure from animals raised as food for rapidly expanding urban markets. Greater wealth was accumulated by landowners at the same time that fewer farmhands were needed to work the land. The accumulated capital and abundant cheap labour created by this revolution in agriculture fueled the development of the Industrial Revolution in the 18th century.

The revolution began in northern England in the 1730s with the development of water-driven machinery to spin and weave wool and cotton. By mid-century James Watt had developed a practical steam engine that emancipated machinery from sites adjacent to waterfalls and rapids. Britain had been practically deforested by this time, and the incessant demand for more fuel to run the engines led to the exploitation of coal as a major industry. Industries were built on the coalfields to minimize the cost of transporting coal over long distances. The increasingly surplus rural population flocked to the new manufacturing areas. Canals and other improvements in the transportation infrastructure were made in these regions, which made them attractive to other industries that were not necessarily dependent on coal and thus prompted development in adjacent regions.

Spread of industrialization

Industrialization outside of England began in the mid-19th century in Belgium and northeastern France and spread to Germany, The Netherlands, southern Scandinavia, and other areas in conjunction with the construction of railways. By the 1870s the governments of the European nations had recognized the vital importance of factory production and had taken steps to encourage local development through subsidies and tariff protection against foreign competition. Large areas, however, remained virtually untouched by modern industrial development, including most of the Iberian Peninsula, southern Italy, and a broad belt of eastern Europe extending from the Balkans on the south to Finland and northern Scandinavia.

During the 20th century Europe has experienced periods of considerable economic growth and prosperity, and industrial development has proliferated much more widely throughout the continent; but continued economic development in Europe has been handicapped to a large degree by its multinational character—which has spawned economic rivalries among states and two devastating world wars—as well as by the exhaustion of many of its resources and by increased economic competition from overseas. Governmental protectionism, which has tended to restrict the potential market for a product to a single country, has deprived many industrial concerns of the efficiencies of large-scale production serving a mass market (such as is found in the United States). In addition, enterprise efficiency has suffered from government support and from a lack of competition within a national market area. Within individual countries there have been growing tensions between regions that have prospered and those that have not. This "core–periphery" problem has been particularly acute in situations where the contrasting regions are inhabited by different ethnic groups.

RESOURCES

Mineral resources. With rocks and structures of virtually all geologic periods, Europe possesses a wide variety of useful minerals. Some, exploited since the Bronze Age, are depleted; others have been greatly consumed since the Industrial Revolution. Useful minerals include those that provide energy, ferrous and nonferrous metals and ferroalloys, and those that furnish materials to the chemical and building industries. Europe has a long and commendable prospecting tradition, but, as in the case of North Sea gas and oil, some surprises are still encountered. In relation to the ever-mounting requirements of its economy, however, Europe—Russia and Ukraine apart—is heavily dependent on mineral imports.

Coal. Europe commands abundant resources of hard and soft coal, which remains of considerable, if declining, importance as a source of power for smelting minerals and for its many by-products. Only exceptionally does northern Europe have coal measures of commercial scale, but coal seams are preserved in Hercynian basins throughout the continent, lying diagonally across Britain, Belgium, The Netherlands, France (especially Lorraine), North Rhine-Westphalia and Saarland (Germany), and Upper Silesia (mainly in Poland but also in the Czech Republic), and in the Donets Basin and Urals. There are numerous fields, small but often—as at Komló (near Pécs in Hungary) and in the Arctic fields of Vorkuta in Russia and Svalbard in Norway—of great locational value. Some, as in southwestern Scotland and southern Belgium, have been worked out or have become uneconomic. Deeper workable seams are sought—in the Ruhr (Germany), for example, and undersea off Yorkshire (England). Major reserves, encompassing mostly hard deposits of coking, anthracite, and steam coal, lie in the Ruhr, the Pennine fields of England, Upper Silesia, and the Donets Basin. Softer brown coal, or lignite, occurs in Germany, the Chomutov fields of Bohemia, and the Moscow-Tula field.

Petroleum and natural gas. Known petroleum and natural gas reserves are, except in Russia, wholly disproportionate to Europe's requirements. The Volga-Ural field is the largest in European Russia; Romania's reserves from the Carpathian and sub-Carpathian zones, once the largest in Europe, no longer meet its needs. Many western European countries have located and exploited reserves of petroleum, particularly Norway and the United Kingdom, which have tapped gas and oil from beneath the North Sea bed. In the late 1980s Romania became a leader in extracting oil from the Black Sea.

Russian reserves

Uranium. Sources of uranium for use in nuclear reactors have been discovered in many European countries, including France (centred on the Massif Central), Spain, Hungary (the Mecsek Mountains), Estonia, Ukraine, and, in lesser amounts, parts of central and eastern Europe.

Iron ores. The largest known iron reserves are found at Krivoy Rog in Ukraine and at Magnitogorsk and near Kursk in Russia. High-quality ores (of 60 percent iron) from the first two sources have become expensive to mine, but the reserves in those two countries are more than sufficient for their needs and those of eastern Europe. The Kursk Magnetic Anomaly, located in southwestern Russia, has iron-rich quartzites. Deposits in other European countries are small and, except in France and Sweden, inadequate for large-scale heavy industry.

Ferroalloy metals. The richest ferroalloy deposits occur in Russia—in the emerged shield rocks of the Kola Peninsula (titanium and molybdenum) and the Urals—and in Ukraine. Nickel also is mined at Pechenga and Kola (Kola Peninsula) and at several Ural sites. The southern Urals also have deposits of manganese, required for basic steel manufacture, but these are dwarfed by the Ukrainian deposit at Nikopol, near the Krivoy Rog iron field, which is the largest and best-located in the world. Other countries

have virtually no significant nickel or tin reserves and only small manganese resources. There are chromium deposits of some scale near the Russian city of Orsk and in the Balkan region, the latter of which also contains antimony and molybdenum. Wolframite (for tungsten) is mined from Iberian Hercynian rocks. Norway has molybdenum and titanium workings, and Finland has deposits of titanium, vanadium, and cobalt—valuable and scarce alloys for special steels. Russia also produces vanadium.

Nonferrous base metals. With notable exceptions, known European reserves are small, partly as a result of the depletion, for example, of Cornish tin and Swedish copper. Deposits yielding copper, often from copper pyrites, are found in Scandinavia, the southern Urals, and Mediterranean lands. Bor (Serbia, Serb.-Mont.) has the largest reserve of copper (low-grade) in Europe; its reserves in lead and, especially, zinc are also high. Mercury is obtained near Kryvyy Rih (Ukraine), in the Balkan region, and in southern Spain. Europe has much bauxite, the principal ore of aluminum, with Greece, Russia, and Hungary having the largest reserves. Nepheline, an alternative raw material for aluminum, is worked near Kola (Russia).

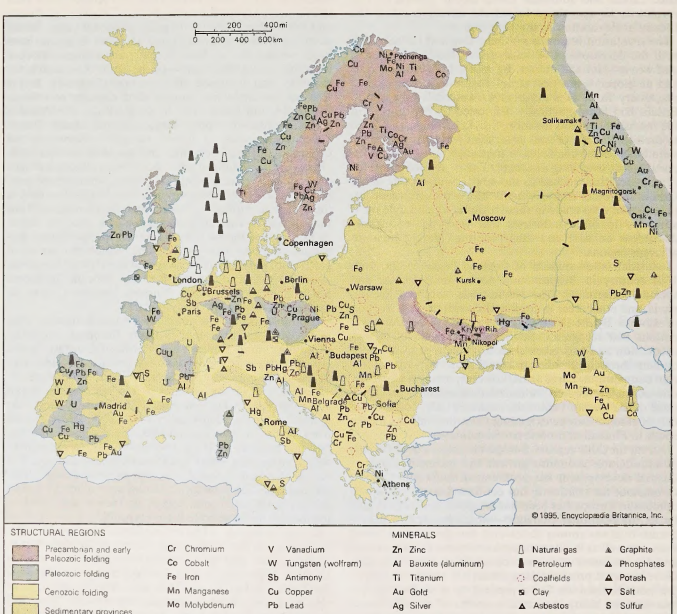
Bauxite reserves

Precious metals. Europe's once widely available reserves of gold appear largely exhausted. Some gold and silver are still produced, mainly in Spain and Sweden.

Nonmetallic deposits. Minerals within this large category are widely available. Clay minerals include fuller's earth—used to cleanse wool and to finish cloth—derived from the decomposition of feldspar. Kaolinite, of similar origin, is valuable as china clay and occurs in a pure form in southwestern England; it surpasses coal as a British export. Rock salt, important in the chemical industry, occurs widely, much of it being precipitated in such geologically ancient salt lakes as the Russian Lake Baskunchak (in the lower Volga basin), which contains strata 130 feet thick. Other salts important for the chemical industry are produced in France and Germany. Europe also has substantial sulfur deposits, and the mining of sulfur in Miocene beds in Sicily gave Italy a virtual monopoly before the opening up of New World deposits in Texas. The carbonate rock dolomite, like talc, is used as a refractory material, as in lining metal furnaces, and is widespread. Graphite, a crystalline form of carbon used as a lubricant and the basis (with clay) of the "lead" in pencils, is worked in Austria, the Czech Republic, and England. Nitrates, for fertilizers and explosives, are made from the air electrolytically in England, Norway, and Russia, and deposits generating potash and phosphate fertilizers are relatively abundant. The Russian apatite (calcium phosphate) deposits of the Kola Peninsula are the world's largest, as are the potash deposits at Solikamsk, in the Urals. Corundum, a hard abrasive, occurs widely. Building materials for cement and bricks, as well as stone, are abundant, although only regionally available, depending on geologic structure. Particular building stones—marble from central Italy, granite from Norway and Scotland—have localized sources. Except in the Urals, precious stones are rare; these mountains also contain the chief European deposit of asbestos.

Building materials

Water resources. The mountainous and upland areas of Europe collect great amounts of surface water, which supply the rivers and lakes; the lowlands, with lower rainfall, thus receive much of their water from the higher portions of their river basins. In the Mediterranean lands, surface water is minimal in summer, exceptions being



Basic structural regions and principal mineral and hydroelectric sites of Europe.

northern and northwestern Iberia, which receives ample rain; the North Italian Plain, which has Alpine rivers, lakes, springs, and summer rain; and the Apennine zone of Italy. In the east, surface water is relatively abundant in Belarus and central and northern Russia, but it decreases to the south and southeast; in the drier regions, however, rivers drain extensive basins, and dams on the Volga and Dnieper (Dnepr) have created enormous reservoirs.

The increasing water requirements of thermal power stations and industry and, to a lesser extent, domestic needs make the little-populated and little-industrialized European highlands, which offer surplus water, indispensable to the lowlands. The pollution of water by effluents containing nonoxidizable detergents from urban areas and by those from oil refineries and chemical and metallurgical plants has reached such proportions in, for example, the section of the Rhine below Basel, the Ruhr region, and Lakes Geneva and Garda as to present serious problems and to incur high reclamation costs. In reaction to water shortages, water is, as in the Thames, recycled many times, a practice that improves river water quality.

Europe is relatively well supplied with water, for the water table is normally not far below the surface in the lowlands, and wells and springs are widely available there; underground water supplies (groundwater) that are held particularly in porous rocks are sporadically utilized through the process of pumping. A trend that appears to be growing is to artificially add to supplies of groundwater and thus integrate surface and underground water; nearly half of Sweden's urban water requirements are thus supplied. High capital costs, rather than an actual lack of water, leave some areas of the continent—notably southwestern Russia near the Caspian Sea and parts of interior Spain and Turkey—in an arid state. The needs of the major European cities and of the industrial regions involve continuing efforts to collect enough water by impounding surface water, by pumping groundwater, and by encouraging the economy, reuse, and reclamation of water.

Recycling of water

Biological resources. Some reference to plant, animal, and human resources is needed to complement any discussion of European resources. Reference has already been made above to what remains of Europe's plant and animal heritage, supplemented as this is by such vigorous developments as the breeding of livestock to specific purposes and the acclimatization of trees and plants of economic value, which have taken place throughout its history.

The human resources of Europe, since they result from the efforts applied at an ever-rising technical level, are in some respects inexhaustible. Although the cultivation of soil and mining and quarrying of metallic minerals were initiated in prehistoric times, the winning of some resources began only in relatively recent times, in response to new needs and technology. The clearing of woodlands for the plow has continued since the early Middle Ages; the cultivation of the steppe lowlands of Ukraine and the lower Danube basin commenced only in the late 18th century. Effective drainage, in which the Dutch have excelled, especially during and after the 17th century, has made use of former marshlands. The large-scale mining of coal and iron ore dates from the Industrial Revolution. Some industries—many of them concerned with the products of the chemical industry and the refining of aluminum—belong to the 20th century, during which electricity was developed as a form of energy and the internal-combustion engine was developed for use on land, sea, and in the air.

Economic growth stages

The concept of stage, too, helps an understanding of Europe's economic development, for the application to industry and agriculture of modern technology and scientific research has reached different parts of the continent successively. Great Britain, as the home of the Industrial Revolution, stimulated economic change in western, central, and northern Europe. Russia and other former Soviet republics and the countries of eastern Europe were mostly late starters, and the pace and scale of their industrialization quickened markedly after 1945. The countries of southern Europe, notably northern Italy, also advanced economically following World War II. Europe is thus a highly developed part of the world, although economic development is uneven regionally.

AGRICULTURE

Distribution. Arable land in Europe covers almost 30 percent of the total area, a favourable comparison, for example, with the United States (20 percent). Figures for individual countries vary sharply, from about three-fifths of the land in Denmark to less than 3 percent in Norway. Europe's industrialization and urbanization tend to conceal the fact that it is a great producer of cereals, roots, edible oils, fibres, fruit, and livestock and livestock products, accounting for more than 90 percent of the world's rye output, two-thirds of the potato and oats output, and two-fifths of the wheat total.

Europe's climatic range has helped to delineate production areas; thus the vine is commercially grown south of about latitude 50° N, and the olive is restricted to Mediterranean climatic regions. Corn (maize), grown mainly for silage, is an important crop in the lower Danubian lowlands and southwestern Russia; it appears also in France and Italy. Rice (in northern Italy) and citrus fruits (in Spain, Sicily, and Cyprus) depend on irrigation. The northern countries grow few cereals (mainly oats) and concentrate on animal husbandry, especially cattle and dairying. Grain cultivation is found in the lowland belt that stretches from eastern Great Britain to the Urals. Wheat is grown on the better soils, oats and rye on the poorer soils and moister lands. Mixed farming and the use of well-tried crop rotations are widely practiced. Viticulture, although widely distributed, is most important in Italy, France, and Germany. As for industrial crops, Russia, Ukraine, and Belarus are the largest producers of flax and hemp, sugar beets (also grown widely elsewhere as a rotation crop), and (except for Belarus) sunflower seeds (for edible oil). Tobacco is raised in Belarus and also is important in Bulgaria, Italy, and Macedonian Greece.

Agricultural organization. Throughout most of the 20th century there were sharp differences in European agricultural organization and regional efficiency. The pattern in the Soviet Union and in most eastern European countries was of collective and state farming; cooperative systems, with or without individual landownership, prevailed elsewhere on the continent, with the consolidation of smaller holdings progressing steadily in western Europe. The capital-intensive agriculture of such western countries as The Netherlands and Great Britain produced markedly higher yields per acre and per person than in the extensive Soviet system, despite the benefits—notably mechanization—brought by collectivization. With the dissolution of the socialist bloc and abandonment of collectivization, however, the system in the East has come to resemble more closely that of the West.

Disparities also exist between north and south. Only 1 percent of the working population of the United Kingdom is engaged in agriculture, but about half the workers in Albania are so engaged. The higher figure indicates high rural population densities, a lack of investment capital, and underemployment. The relative use of fertilizers—high in The Netherlands and relatively low in Spain and Portugal—hints also at the range of crop productivity.

Irrigated areas, lying mainly in southeastern Spain, the North Italian Plain, and Mediterranean France, are small but disproportionately productive. Long-term prospects for using the irrigation capacity of the lower Danube and Volga are good.

Livestock farming and dairying associated with pigs and poultry is characteristic of European farms, except in the Mediterranean lands, which are better adapted to sheep and goats. Europe produces more than a third of the world's meat, chiefly beef, pork, and bacon, but this is insufficient to meet rising living standards. Domestic production of wool, hides, and leather also is insufficient.

Specialty crops of western Europe

Special features of western European farming include market gardens and the greenhouse production of tomatoes, cucumbers, green vegetables, and flowers for the urban markets. Still another feature is the production of *primeurs:* table fruit, new potatoes, vegetables, salad crops, and flowers, produced when prices are high and made possible by the early arrival of spring to the coasts of Brittany, Cornwall, and southern France.

The great advances made in agronomic science during



Agricultural regions of Europe.

the 20th century have benefited all of Europe, but the hazards of harvest shortfalls caused by climate have not been eliminated. It has been necessary to make intermittent emergency, as well as regular, claims on areas with grain surpluses overseas. Since the 1960s, harvest shortfalls and increased feed requirements have impelled the Soviet Union and its successor states to import large amounts of grain, especially from the United States and Canada.

INDUSTRY

Mining. Mining provides employment in all countries, although for smaller numbers as mechanization is applied. High-grade iron ores are mined in Ukraine at Krivoy Rog, in Russia near Kursk and Magnitogorsk, and in Arctic Sweden and Norway; these are supplemented by the low-grade minette ores of Lorraine (France) and Luxembourg, low-grade (quarried) Jurassic ores of England, and low-grade Spanish ores. Europe, including the European part of Russia, accounts for about one-fourth of the world's coal production and roughly three-fourths of its lignite. There was very little increase in coal production during the late 20th century, because European countries have made greater use of other forms of energy, especially oil, nuclear power, natural gas, and hydroelectricity. The chief coal producers are Poland (Upper Silesia), Great Britain, Germany (the Ruhr and Saarland), Ukraine, and Russia. The Donets Basin accounts for a considerable amount of coal production in the east. Germany also is the world's chief source of lignite, which is mined in Slovakia and west central Russia as well. Many mineral deposits are of only local interest, but, as a whole, Europe produces a fair proportion of the world's bauxite, copper, lead, and zinc. Minerals of more than domestic importance are natural gas in The Netherlands; bauxite in Greece, the Balkan region, and Hungary; petroleum from the Volga-Ural region and apatites from Kola in Russia; manganese in Ukraine; and china clay in England.

Coalfield-based industry

Heavy industry and engineering. The change from charcoal to coke as fuel in blast furnaces led to the localization of Europe's iron and steel industries on its coalfields to economize transport costs, although imported iron ore, cheap American coal, electric furnaces, and technological efficiency have loosened this tie. Thus, Northumberland and Durham in England, North Rhine-Westphalia, Upper Silesia, and the Donets Basin have their coalfield furnaces and mills, while others are grouped near sources of the ore, as at Krivoy Rog and in Lorraine, or at such convenient estuary or port sites as Port Talbot (southern Wales), Genoa (Italy), and Dunkirk (France). Europe produces about half of the world's steel, with the countries of the European Union accounting for about one-third of the total European output. Europe also produces almost one-third of the world's iron ore. Steel-using industries that make heavy machine tools and mining, smelting, construction, and electrical equipment favour coalfield locations, while those engaged in shipbuilding and motor-vehicle and aircraft construction show a wider distribution, including new sites.

Chemical industries. Covering many products, chemical industries have expanded greatly since 1945, partly in relation to hydroelectricity generation and partly as a result of the market-oriented use of refinery by-products. Many heavy chemicals are produced on the coalfields, notably in the Ruhr, where by-products of coke ovens and metallurgical plants are available. Other chemical industries make use of Europe's deposits of salt, potash, phosphates, and sulfur; and the industry has been revolutionized by the increasing production of synthetic rubber, plastics, synthetic fibres, detergents, insecticides, and fertilizers, particularly from petrochemicals.

Manufacturing, lumbering, and fisheries. A wide range of light consumer industries is found throughout Europe, but some countries have reputations for specialty goods, as in the case of English, Italian, and Dutch bicycles, Swedish and Finnish glass, Parisian perfumes and fashion goods, and Swiss precision instruments and chocolate. The United Kingdom's once-leading textile industry now concentrates on high-quality goods, including many synthetic fibres, of which, together with Germany, France, and Italy, the United Kingdom is a large producer.

Specialty goods

The timber and fisheries extractive industries, now mechanized, are of considerable scale. Russia, Sweden, and Finland are major producers of softwood and hardwood and exporters of timber, wood pulp, and newsprint. Fishing is a large industry for Norway, Iceland, and Russia; catches yield not only food for humans but materials for many subsidiary industries. Fishing also is important in the United Kingdom, Ukraine, and France.

Handicrafts and other industries. Of proportionately small but notable importance in a continent where the economies of mass production involve large-scale standardization and mechanization, traditional handicrafts survive to serve a wide market, including that of tourists who seek specialty goods. Knitwear and Harris tweed are produced by crofters in the Scottish islands; traditional costumes are made in many eastern European countries; and custom tailoring for men, like dressmaking for women, survives as a supplement to ready-made clothing. Artistic pottery making is another active craft.

Some other European industries fall but uneasily into the preceding categories. Printing and publishing, especially in English, French, German, and Russian, are substantial industries that have worldwide effects, notably in the educational field. Europe is a large producer of pharmaceutical drugs and produces such world-famous beverages as the wines of the west and south, the northern beers, and, not least, whiskey, the status drink from Scotland. Technological and scientific researches are advanced, particularly at such facilities as the European Organization for Nuclear Research (CERN) near Geneva. The outstanding growth industry of tourism—supplementing business, professional, and student travel—brings employment and foreign exchange to many Europeans, especially in the Mediterranean countries, with their combination of sunshine, beaches, scenery, and historical monuments. Europe, with nearly 60 percent of international tourism receipts, is the tourist mecca of the world.

Growth of tourism

POWER

The message of the Industrial Revolution was that mechanical energy, when it is harnessed to machines, could so supplement human muscle and animal power as to produce revolutionary changes in the scale and pace of factory production. Contemporary Europe, covering less than one-tenth of the inhabited earth and with only one-seventh of its population, uses about one-fourth of the world's energy.

Coal and hydroelectric power. Coal, used to drive steam engines and, as coke, in the smelting of metals, long held the predominant position. During the early 21st century, coal continued to provide energy to coalfield-based industries and was still important for the production of electricity.

Hydroelectricity has been markedly developed where precipitation and landforms provide good opportunities to dam rivers, as in northern and Alpine Europe and southwestern Russia. Norway, for example, derives almost all its electric power from this source; Spain, Portugal, Switzerland, Austria, Sweden, and the Balkan region derive a large fraction. France has developed power-consuming industries, such as aluminum refining, close to the Alpine and Pyrenean generating sites.

Other power sources. In other countries, hydroelectricity contributes very little, and petroleum and natural gas claim a large share of the energy consumed. By the early 21st century petroleum and natural gas together accounted for about one-seventh of the world's energy consumption. Natural gas has replaced coal gas in many parts of Europe, including Russia, Romania, and Great Britain. Fuel oil is widely used by diesel locomotives and electricity-generating stations and for space heating. Geothermal heat—using underground waters heated by volcanic action—is available in Italy and Iceland, while Ireland, which also lacks both coal and oil, makes efficient use of abundant peat resources. Nuclear-reactor electricity generation, promoted by the European Atomic Energy Community (Euratom) in the EU, provides, as in Russia and other eastern European countries, a significant source of electrical energy. Wind (in Denmark and Germany) and tidal (in France) power have also been harnessed.

Nuclear-reactor electricity generation

TRADE

Internal and external trade, both by land and by sea, always have been a vigorous part of Europe's economy, no less so in the early 21st century when Europe faced such strong competitors as the United States and Japan. Trade is made necessary by the regional specialization of production, largely initiated by capitalist enterprise in the past and now predominantly guided by national and, more recently, supranational policy decisions. Geology in large part accounts for the localization of extraction of Swedish iron ore and Russian petroleum, for example, while climate localizes the production of olive oil and citrus fruits. Europe acquired a central position in modern times in the well-settled Northern Hemisphere, which oceanic and air transport systems still exploit. Simultaneously providing large managerial, market, and labour-force attractions, Europe inevitably attracts extra-European traders, with its ever more sophisticated industry producing outstanding exports and its large importation of petroleum products, metals, other raw materials, and foodstuffs.

Within the continent, there was a distinction for much of the 20th century between the general trade policy of western Europe and that of the now-disbanded socialist bloc. Prior to the late 1960s the Soviet Union and the eastern European countries adhered to the doctrine of economic self-sufficiency with more interregional than international trade. In the late 1960s and the '70s these trading patterns began to change. Improved relations between the East and the West enabled the socialist countries to meet an increased amount of their technological and agricultural needs with imports from Western countries. As the countries of eastern Europe abandoned socialism—and especially since Germany was reunited and the Soviet Union was dissolved into its constituent republics—interest in external trade has grown dramatically in those countries. The nations of western Europe, on the other hand, have always relied heavily on international trade.

Europe plays the leading role in world commerce, accounting for about two-fifths of the total of world exports and imports. The bulk of this trade is carried on by the Western countries, which own much of the world's oceangoing tonnage. For long periods of time, most of the European countries held political dependencies overseas where they created captive markets, and this imperialist trading momentum has persisted. EU countries have former colonial territories as associate members, and, similarly, the Commonwealth nations engage in much trade, now strictly competitive, with the United Kingdom; the accession of the United Kingdom to the Common Market in 1973, however, resulted in a decline in the proportion of British trade with the Commonwealth.

One of the continuing international difficulties that Europe has faced concerns currency and fluctuating exchange rates, which at times have affected the trading capability of various countries. European financiers play an important world role, as do a variety of such finance-related industries as banking, insurance, and shipping.

Internal trade. Within each European country a wide variety of goods is moved continually from ports and production centres to urban markets. Miscellaneous home-produced goods also are traded to consumer centres. Imported goods include fuels, tropical foodstuffs and drinks, raw materials, textile fibres, metals and metallic ores, and a wide range of manufactured goods.

Active trading within groups of countries that have associated primarily for this purpose and to rationalize and so increase the profitability of their national economies has advanced. The policies of the EU have been directed toward economic specialization in increasingly interdependent member countries. Germany supplies coking coal and chemicals to France, which provides Belgium with iron ore from Lorraine. Steel is moved to extranational markets, and Dutch natural gas is piped to France, Belgium, and Germany. Specialty foodstuffs—wines, cheeses, spring vegetables, and fruit—find an enlarged market far beyond their production centres, as do such manufactured items as fashion goods, automobiles, and major household appliances. Although the former socialist countries no

Trading blocs

longer operate as a trading bloc, they continue to direct much of their trade to each other, with Russia remaining preeminent as a producer and a major market. Russia and the former Soviet republics supply petroleum, manganese, iron, and chromium ores, as well as cotton and other textile fibres; they receive machinery, textiles, and consumer goods.

The European Free Trade Association (EFTA) also has encouraged trade between its members, who exchange such complementary, rather than similar, products as Swedish and Finnish timber and Swiss watches and food products. In 1977 a free-trade agreement went into effect between the Common Market and the EFTA. The agreement eliminated tariffs on most industrial goods originating in the member countries, thereby increasing trade between the countries in the two blocs.

Trade between the West and the East increased markedly during the late 20th century. Russian natural gas was sold to Italy, France, and Germany, and Western markets also were used for the sale of gold and diamonds in exchange for ships, machinery, and chemicals. Eastern European countries supplied automobiles, canned salmon and caviar, vodka, Polish bacon, Czech glass, and Hungarian and Yugoslav wines.

Given the continental scale of the former Soviet Union, the regional trade of Russia and the other republics, carried largely by rail and supplemented by pipelines and an elaborate waterway system, deserves special attention. From the south, grain, meat, vegetable oils, sugar, tobacco, wine, and fruits are moved to central and northern Russia, where the consumption of such items exceeds local production; dried fish and salt are carried up the Volga. Timber is moved from northern areas, including the Urals, to largely unforested southern regions, and Donets Basin coal is shipped by canal to Volgograd.

External trade. A major part of the external trade of European countries is with each other, since—with regional specialization, dense populations, and relatively high standards of living—they provide strong markets. For the Common Market countries, as well as for those of northern Europe (EFTA), this trade proportion is very high. Nevertheless, a substantial amount of trading takes place among EC and EFTA members; and, especially in the United Kingdom and Germany, a vigorous two-way trade with the United States is conducted. Much foreign trade is still intraregional in eastern Europe and the republics of the former Soviet Union, but, for countries such as Czechoslovakia, Hungary, and Poland, the proportion of their external trade with the West is growing rapidly. European trade also extends to all other parts of the world, including the developing countries, where—in exchange for manufactured products—vital supplies of energy, raw materials, metals, ores, and foodstuffs are obtained.

North American trade links

The extracontinental exports of Europe include machine tools, automobiles, aircraft, chemicals (including pharmaceutical drugs), and such consumer items as clothing, textiles, books, expert services, and works of art. Western Europe depends heavily on imported petroleum from the Middle East, Algeria, and Libya and on many imported raw materials and metals. Europe imports much natural rubber, tea, coffee, cacao, cane sugar, vegetable oilseeds, tobacco, and fruit—fresh, canned, and dried—although it has attempted to lessen its dependence on imported agricultural products with greater domestic production and the manufacture of synthetic substitutes for natural fibres.

TRANSPORTATION

Roads. Eastern Europe is relatively deficient in engineered motor roads compared with western Europe, where a network of high-speed, limited-access highways provide fast movement for commerce and travel. Motorable roads have become more widely available; those of Spain and Ireland in particular have improved, and road tunnels now supplement railway tunnels beneath the Alpine passes. Animal transport has minimal importance yet survives locally: the horse-drawn cart may still be seen in east central Europe; and the ox-drawn plow and the loaded ass, mule, and donkey—surefooted in rough, hilly country—are still used in parts of southern Europe. In regions with long, snowy winters such as northern Russia, the dog- or reindeer-drawn sled is used.

Railways. Railways link European ports with their hinterlands and fan out from capitals and major cities to points on the international frontiers where they meet the railway system of their neighbours. In some cases—notably from France to Spain and from Belarus and Ukraine to Poland—this involves a change of gauge. Underground and suburban railways also play an indispensable role for metropolitan commuters. Railways permit passage between the western and eastern European extremities but not quite to the extreme north; they have lost some of their passengers and freight to the automobile, coach, and truck, and many uneconomic local lines have been closed. Even so, rail services have notably improved with the use of electrified track or diesel locomotives, faster intercity passenger trains, and container freight trains. Railways remain all-important in Russia and the other republics of the former Soviet Union.

Waterways and pipelines. Seaports have been modernized and enlarged to deal more efficiently with the increasing size of ships and volume of oceanic trade. Even landlocked Switzerland has seagoing ships that use Dutch port facilities. The United Kingdom, Norway, and Greece also hold large freighter tonnages for hire.

Inland waterway transport, slow but cheap, is regionally important for the carriage of heavy and bulky commodities. The best waterways—the Rhine below Rheinfelden and the Danube below Belgrade—can carry 1,500-ton barges. The navigable Rhine has the legal status of an international waterway open to all users. Other rivers and canals are usable by smaller vessels. The Volga, however, is a valuable waterway linking Moscow with Caspian ports and, via the Volga–Don Shipping Canal, gives water access to the Donets Basin.

Barge carriers

Giant tankers, up to and beyond 300,000 gross registered tonnage and too deep in draught for most seaports, deliver their cargoes by pipelines that—for petroleum, natural gas, and water—provide the cheapest overland form of transport. They have been built in the United Kingdom for North Sea gas and oil; in France, Spain, and Italy for North African oil; and within and beyond Russia and Ukraine, where crude oil is carried by pipeline from the Volga-Ural field to eastern European refineries.

Airways. Air services between principal European cities and to all parts of the world are extensively organized. Airports at London, Frankfurt am Main, Paris, Stockholm, Amsterdam, and Moscow stand out as those of first importance. Passengers, mail, and commodities of high value in relation to their weight—such as gold and early spring flowers—make use of air transport.

(W.G.E./T.M.P./Ed.)

EUROPEAN GEOGRAPHIC FEATURES OF SPECIAL INTEREST

Landforms

THE ALPS

The Alps are a small segment of a discontinuous mountain chain that stretches from the Atlas Mountains of North Africa across southern Europe and Asia to beyond the Himalayas. They extend north from the subtropical Mediterranean coast near Nice, France, to Lake Geneva before trending east–northeast to Vienna. There they touch the Danube River and meld with the adjacent plain. The Alps form part of nine nations: France, Italy, Switzerland, Germany, Austria, Slovenia, Croatia, Bosnia and Herzegovina, and Serbia and Montenegro; however, only Switzerland and Austria can be considered true Alpine nations. Some 750 miles (1,200 kilometres) long and more than 125 miles wide at their broadest point between Garmisch-Partenkirchen, Ger., and Verona, Italy, the Alps are the most prominent of western Europe's physiographic regions.

Though they are not as high and extensive as other mountain systems uplifted during the Tertiary period—such as the Himalayas and the Andes and Rocky mountains—they are responsible for major geographic phenomena. The Alpine crests isolate one European region from another and are the source of many of Europe's major rivers, such as the Rhône, Rhine, Po, and numerous tributaries of the Danube. Thus, waters from the Alps ultimately reach the North, Mediterranean, Adriatic, and Black seas. Because of their arclike shape, the Alps separate the marine west-coast climates of Europe from the Mediterranean areas of France, Italy, and the Balkan region. Moreover, they create their own unique climate based on the local differences in elevation and relief and the location of the mountains in relation to the frontal systems that cross Europe from west to east. Apart from tropical conditions, most of the climates found on the Earth may be identified somewhere in the Alps, and contrasts are sharp.

A distinctive Alpine pastoral economy that evolved through the centuries has been modified since the 19th century by industry based on indigenous raw materials, such as the industries in the Mur and Mürz valleys of southern Austria that used iron ore from deposits near Eisenerz. Hydroelectric power development at the end of the 19th and beginning of the 20th centuries, often involving many different watersheds, led to the establishment in the lower valleys of electricity-dependent industries, manufacturing such products as aluminum, chemicals, and specialty steels. Tourism, which began in the 19th century in a modest way, has become, since the end of World War II, a mass phenomenon. Thus, the Alps have become a summer and winter playground for millions of European urban dwellers and annually attract tourists from around the world. Because of this enormous human impact on a fragile physical and ecological environment, the Alps are the most threatened mountain system in the world.

Physical features. *Geology.* The Alps emerged during the Alpine orogeny, an event that began about 70 million years ago as the Mesozoic era was drawing to a close. A broad outline helps to clarify the main episodes of a complicated process. At the end of the Paleozoic era, about 245 million years ago, eroded Hercynian mountains, similar to the present Massif Central in France and Bohemian Massif embracing parts of Germany, Austria, Poland, and the Czech Republic, stood where the Alps are now located. A large landmass, formed of crystalline rocks and known as Tyrrhenia, occupied what is today the western Mediterranean basin, whereas much of the



The Alps mountain ranges.

rest of Europe was inundated by a vast sea. During the Mesozoic (245 to 66.4 million years ago) Tyrrhenia was slowly leveled by the forces of erosion. The eroded materials were carried southward by river action and deposited at the bottom of a vast ocean known as the Tethys Sea, where they were slowly transformed into horizontal layers of rock composed of limestone, clay, shale, and sandstone.

During the middle Tertiary period, about 44 million years ago, relentless and powerful pressures from the south first formed the Pyrenees and then the Alps, as the deep layers of rock that had settled into the Tethys Sea were folded around and against the crystalline bedrock and raised with the bedrock to heights approaching the present-day Himalayas. These tectonic movements lasted until nine million years ago. Tyrrhenia sank at the beginning of the Quaternary period, about 1.6 million years ago, but remnants of its mass, such as the rugged Estérel region west of Cannes, France, are still found in the western Mediterranean. Throughout the Quaternary period, erosive forces gnawed steadily at the enormous block of newly folded and upthrust mountains, forming the general outlines of the present-day landscape.

Glaciation

The landscape was further modeled during the Quaternary by Alpine glaciation and by expanding ice tongues, some reaching depths of nearly one mile (1.6 kilometres), that filled in the valleys and overflowed onto the plains. Amphitheatre-like cirques, arête ridges, and majestic peaks such as the Matterhorn and Grossglockner were shaped from the mountaintops; the valleys were widened and deepened into general U-shapes, and immense waterfalls, like the Staubbach and Trümmelbach falls in the Lauterbrunnen Valley of the Bernese Alps, poured forth from hanging valleys hundreds of feet above the main valley floors; elongated lakes of great depth such as Lake Annecy in France, Lake Constance, bordering Switzerland, Germany, and Austria, and the lakes of the Salzkammergut in Austria filled in many of the ice-scoured valleys; and enormous quantities of sands and gravels were deposited by the melting glaciers, and landslides—following the melting of much of the ice—filled in sections of the valley floors. The hills east of Sierre in the Rhône valley are an example of this last phenomenon, and they mark the French-German language divide in this area.

When the ice left the main valleys, there was renewed river downcutting, both in the lateral and transverse valleys. The river valleys have been eroded to relatively low elevations that are well below those of the surrounding mountains. Thus, Aosta, Italy, in the Pennine Alps, and Sierre, Switz., look up to peaks that tower a mile and a half above them. In the valley of the Arve River near Mont Blanc, the difference in relief is more than 13,100 feet.

Glaciation therefore modified what otherwise would have been a harsher physical environment: the climate was much milder in the valleys than on the surrounding heights, settlement could be established deeper into the mountains, communication was facilitated, and soils were inherently more fertile because of morainic deposits. Vigorous glacial erosion continues in modern times. Many hundreds of square miles of Alpine glaciers, such as those in the Ortles and Adamello ranges and such deep-valley glaciers as the Aletsch Glacier near Brig, Switz., are still found in the Alps. The summer runoff from these ice masses is instrumental in filling the deep reservoirs used to generate hydroelectricity.

Physiography. The Alps present a great variety of elevations and shapes, ranging from the folded sediments forming the low-lying pre-Alps that border the main range everywhere except in northwestern Italy to the crystalline massifs of the inner Alps that include the Belledonne and Mont Blanc in France, the Aare and Gotthard in Switzerland, and the Tauern in Austria. From the Mediterranean

Divisions of the Alps

to Vienna, the Alps are divided into Western, Central, and Eastern segments, each of which consists of several distinct ranges.

The Western Alps trend north from the coast through southeastern France and northwestern Italy to Lake Geneva and the Rhône valley in Switzerland. Their forms include the low-lying arid limestones of the Maritime Alps near the Mediterranean, the deep cleft of the Verdon Canyon in France, the crystalline peaks of the Mercantour Massif, and the glacier-covered dome of Mont Blanc, which at 15,771 feet (4,807 metres) is the highest peak in the Alps. Rivers from these ranges flow west into the Rhône and east into the Po.

The Central Alps occupy an area from the Great St. Bernard Pass east of Mont Blanc on the Swiss-Italian border to the region of the Splügen Pass north of Lake Como. Within this territory are such distinctive peaks as the Dufourspitze, Weisshorn, Matterhorn, and Finsteraarhorn, all 14,000 feet high. In addition, the great glacial lakes—Como and Maggiore in the south, part of the drainage system of the Po; and Thun, Brienz, and Lucerne (Vierwaldstättersee) in the north—fall within this zone.

The Eastern Alps, consisting in part of the Rätische range in Switzerland, the Dolomite Alps in Italy, the Bavarian Alps of southern Germany and western Austria, the Tauern Mountains in Austria, and the Julian Alps in Northeastern Italy and Northern Slovenia, are synonymous with a northerly and southeasterly drainage pattern. The Inn, Lech, and Isar rivers in Germany and the Salzach and Enns in Austria flow into the Danube north of the Alps, while the Mur and Drau (Austria) and Sava (western Balkan region) rivers discharge into the Danube east and southeast of the Alps. Within the Eastern Alps in Italy, Lake Garda drains into the Po, whereas the Adige, Piave, Tagliamento, and Isonzo pour into the Gulf of Venice.

Differences in relief within the Alps are considerable. The highest mountains, composed of autochthonous crystalline rocks, are found in the west in the Mont Blanc massif and also in the massif centring on Finsteraarhorn (14,022 feet) that divides the cantons of Valais and Bern. Other high chains include the crystalline rocks of the Mount Blanche nappe—which includes the Weisshorn (14,780 feet)—and the nappe of Monte Rosa Massif, sections of which mark the frontier between Switzerland and Italy. Farther to the east, Bernina Peak is the last of the giants over 13,120 feet (4,000 metres). In Austria the highest peak, the Grossglockner, reaches only 12,457 feet; Germany's highest point, the Zugspitze in the Bavarian Alps, only 9,718 feet; and the highest point of Slovenia and the Julian Alps, Triglav, only 9,396 feet. Some of the lowest areas within the Western Alps are found at the delta of the Rhône River where the river enters Lake Geneva, 1,220 feet. In the valleys of the Eastern Alps north of Venice, elevations of only about 300 feet are common.

Climate. The location of the Alps, as well as the great variations in their elevations and exposure, give rise to extreme differences in climate, not only among separate ranges but also within a particular range itself. Because of their central location in Europe, the Alps are affected by four main climatic influences: from the west flows the relatively mild, moist air of the Atlantic; cool or cold polar air descends from northern Europe; continental air masses, cold and dry in winter and hot in summer, dominate in the east; and, to the south, warm Mediterranean air flows northward. Daily weather is influenced by the location and passage of cyclonic storms and the direction of the accompanying winds as they pass over the mountains.

Temperature extremes and annual precipitation are related to the physiography of the Alps. The valley bottoms clearly stand out because generally they are warmer and drier than the surrounding heights. In winter nearly all precipitation above 5,000 feet is in the form of snow, and depths from 10 to 33 feet or more are common. Snow cover lasts from approximately mid-November to the end of May at the 6,600-foot level, blocking the high mountain passes; nevertheless, relatively snowless winters can occur. Mean January temperatures on the valley floors range from 23° to 39° F (−5° to 4° C) to as high as 46° F (8° C) in the mountains bordering the Mediterranean, whereas mean July temperatures range between 59° and 75° F (15° and 24° C). Temperature inversions are frequent, especially during autumn and winter, and the valleys often fill with fog and stagnant air for days at a time. At those times the levels above 3,300 feet can be warmer and sunnier than the low-lying valley bottoms. Winds can play a prominent role in daily weather and microclimatic conditions.

The foehn

A foehn wind can last from two to three days and blows either south–north or north–south, depending on the tracking of cyclonic storms. The air mass of such a wind is cooled adiabatically as it passes upward to the mountain crests, which precipitates either rain or snow and retards the rate of cooling. When this drier air descends on the lee side, it is adiabatically warmed by compression at a constant rate and therefore has a higher temperature at the same altitude than when it began its upward flow. Snow in the affected areas disappears rapidly.

Avalanches, one of the great destructive forces of nature, are an ever-present danger during the period from late November to early June. Though occurring wherever there are high mountains, open slopes, and heavy snowfalls, avalanches are a greater hazard in the Alps than in other mountain ranges because of the relatively high population density and the expansion of winter tourism. Avalanches not only cause widespread damage but, by carrying down large quantities of rock from the mountain slopes to the valley floors, also are significant agents of erosion. Most avalanches follow well-defined paths, but much of the fear of avalanches is related to the difficulty of predicting where and when they will strike.

Plant and animal life. Several vegetation zones that occur in the Alps reflect differences in elevation and climate. A variety of species of deciduous trees grow on the valley floors and lower slopes; these include linden, oak, beech, poplar, elm, chestnut, mountain ash, birch, and Norway maple. At higher elevations, however, the largest extent of forest is coniferous; spruce, larch, and a variety of pine are the main species. For the most part, spruce dominance reaches its upper limit at approximately 7,200 feet in the Western Alps. Better able to resist conditions of cold, lack of moisture, and high winds, larch can grow as high as 8,200 feet and are found interspersed with spruce at lower elevations. At the upper limits of the forests are hardy species such as the Arolla pine that generally do not grow below the 5,000-foot level; this slow-growing tree can live for 350–400 years and in exceptional cases up to 800 years. Its wood, strongly impregnated with resin, decays very slowly and was formerly prized for use in the construction of chalets. The area of Arolla pine have been so reduced that cutting the trees is strictly controlled. Above the tree line and below the permanent snow line, a distance of about 3,000 feet, are areas eroded by glaciation that in places are covered with lush Alpine meadows. There sheep and cows are grazed during the short summer, a factor that has helped lower the upper limits of the natural forest. These distinctive mountain pastures—called *alpages*, from which both the names of the mountain system and the vegetational zone are derived—are found above the main and lateral valleys; the spread of invasive weeds, pollution from animal wastes, and erosion from ski-related development limit their carrying capacity. In the southern reaches of the Maritime Alps and the southern Italian Alps, Mediterranean vegetation dominates, with maritime pine, palm, sparse woodland, and agave and prickly pear evident.

The *alpages*

A few species of animals have adapted well to the higher mountains. Bears have vanished, but the ibex, which like the chamois is endowed with extraordinary nimbleness, was saved by Italian royal game preserves. Marmots hibernate in underground galleries. The mountain hare and the ptarmigan—a grouse—assume a white coat for winter. Several national parks amid the ranges ensure preservation of the native fauna.

Human impact on the Alpine environment. The early travelers to the Alps were greatly inspired by the pristine beauty of what they saw, and from their inspiration sprang the modern popularity of the Alpine region. With popularity, however, came growth; and the impact of so many people has caused a steady degradation of the Alpine environment since the mid-20th century. This has resulted in air of poorer quality; water pollution in rivers and lakes; a rise in noise pollution; slope erosion caused by the construction of ski slopes and roads; dumping, often indiscriminately, of solid and organic waste; erosion from the quarrying of rock, sand, and gravel for construction; and forests weakened by acid rain. Slowly, the unique landscape and flora of the Alps that so inspired the early travelers is being irrevocably altered.

Most conspicuous, perhaps, is the obvious transformation of the landscape. The main river valleys have been converted into linear conurbations of concrete and asphalt; and, in order to accommodate the expanding tourist trade, many villages in the higher lateral valleys have taken on the character of lowland suburbs. A highly visible result of this growth is the serious decline in air quality. Pollution from factories adds to that from home heating and motor vehicle exhausts, the situation aggravated by temperature inversions and weather conditions that often produce little wind. Many of the larger Alpine cities experience severe local air pollution, and some of the valleys can be filled with impure air for weeks at a time.

Pollution

The people. *Settlement.* Humans have been living in the Alps since Paleolithic times, 60,000 to 50,000 years ago. They hunted game and left their artifacts in various sites from the Vercors near the Isère valley in France to the Tieglhohle above Taupliz in Austria. After the retreat of the Alpine glaciers, 4,000 to 3,000 years ago, the valleys were inhabited by Neolithic peoples who lived in caves and small settlements, some of which were built on the shores of the Alpine lakes. Sites have been discovered near Lake Annecy, along the shores of Lake Geneva, in the Totes Mountains in Austria, and in the Aosta and Camonica Valleys in Italy. The latter valley is noted for some 20,000 rock engravings that leave an invaluable picture of more than 2,000 years of habitation.

From 800 to 600 BC Celtic tribes attacked the Neolithic encampments and forced their inhabitants into the remote valleys of the Alps. In the west the area around the juncture of France, Switzerland, and Italy was occupied by the Celts; the modern urban centres of the region, including Martigny, Switz., Aosta, Italy, and Grenoble, Fr., owe their origin to these people. The Celts also penetrated the valleys of Graubünden canton in eastern Switzerland, but the great centre of Celtic culture was found at Hallstatt, the site of a small settlement in Upper Austria. Because of rich archaeological finds there the name Hallstatt has become synonymous with the late Bronze and early Iron ages in Europe, a period dating from about 1000 to 500 BC. The Celts began to open the high Alpine passes for trade routes.

The Romans enlarged the old Celtic villages and built many new towns both in the valleys leading up to the Alps and within the Alps themselves. Villa Aniciaca (modern Annecy, Fr.), Octodurus (Martigny), Augusta Praetoria (Aosta), and Virunum (Zollfeld, Austria) flourished under Roman rule. The Romans improved water supplies and constructed arenas and theatres, the best preserved of which is in Aosta. Control of the Alpine passes was the key to Roman expansion, and they were enlarged from trails to narrow roads. The passes that linked the Roman outposts (*e.g.*, Great St. Bernard, Splügen, Brenner, and Plöcken) were particularly important. The first of the "barbaric" incursions took place in AD 259, and by 400 Roman control of the Alps had disintegrated.

The lands of the Romanized Celts were occupied by Germanic tribes that included the Burgundians, Alemanni, and Lombards. During the 8th and 9th centuries the Alpine lands became part of Charlemagne's Holy Roman Empire. The Treaty of Verdun (843) divided the empire among Charlemagne's grandsons, and in 888 further partition resulted in the basic linguistic differences that have endured until the present. The unity that was imposed on the Alps by the Celts, Romans, and barbarians disappeared during the Middle Ages. For the most part, each valley lived apart and isolated from its neighbours. Much of the history of Alpine peoples after the Roman domination, mirroring that of Europe as a whole, was characterized by an expedient and continuous shifting of religious and political alliances. The isolation of the Alpine peoples was broken by the Industrial Revolution and the coming of the railways that penetrated the Alps via great tunnels.

Partitions of Alpine lands

Languages. French is spoken in the Western Alps, including the Swiss cantons of Vaud and Valais, and in the northwestern Italian region of the Valle d'Aosta. Ostensibly bilingual, the Valle d'Aosta has not been able to resist

the impact of Italianization, and the use of French in daily affairs is confined to certain of the lateral valleys. Italian is spoken in the Central and Eastern Alps of Italy and in the Swiss canton of Ticino. The German language is used throughout the Central and Eastern Alps of Switzerland, Germany, and Austria, as well as in the Alto Adige region of Italy (before World War I the Südtirol area of Austria). There are pockets of Ladin and Friulian peoples in the Eastern Alps of northeastern Italy, and Slovenian is spoken in Slovenia and the adjacent Alpine border regions with Italy and Austria. Roman Catholicism is the main religion throughout the Alps, although there are regions that are predominantly Protestant, such as the Swiss cantons of Vaud and Bern. The Swiss canton of Graubünden reflects the diversity of languages and religion in the Alps, where some 45 percent of its population is Protestant and 50 percent Catholic; 60 percent speak German, about 15 percent Italian, and 20 percent Romansh. Added to the mixture of indigenous languages is the babel created by the variety of foreign seasonal workers, without whom the tourist industry, especially in Switzerland, would collapse.

The economy. *Agriculture.* Before the mid-19th century the economic basis of the Alps was predominantly agricultural and pastoral. Though since then there has been widespread abandonment of farms, especially in the high valleys of France and Italy and in western Austria, agriculture still survives in favoured locations both in the main and lateral valleys. The hot and dry Rhône valley in Switzerland, between Sierre and Martigny, is an intensive area of irrigated fruit and vegetable cultivation, and both the valley floor and slopes of the mountains have extensive vineyards from which excellent wines are made. Above Visp are some of the highest vineyards in the world, reaching more than 4,250 feet. Other regions of viticulture include the Alto Adige region in northern Italy, Ticino, and the southern regions of the Alps. Villagers in such locations as Chandolin in the Swiss Anniviers Valley—which at 6,561 feet is the highest settlement inhabited yearround in the Alps—cut grass for feeding dairy cows, but most of the agriculture and pastoralism in the high valleys exists as hobby farming or second-income enterprises.

Viticulture

Mining and manufacturing. The mainstay of the modern Alpine economy is a combination of mining and quarrying, manufacturing, industries, and tourism. Mining has been carried out since Neolithic times and is still significant in the Erzberg of Austria, where iron has been extracted from the mountain since the Middle Ages. Near Cluse, in the pre-Alps of Haute-Savoie not far from Geneva, a region of watchmaking, screw cutting, component manufacturing, and related industries emerged in the first quarter of the 19th century and evolved into one of the most concentrated industrial locations of its type in the world. Large steel mills were located in Aosta and in the Mur and Mürz valleys because of local supplies of iron and coal. In addition, pulp and paper plants that utilized the Alpine forests were established in the Eastern Alps of Austria. With the development of hydroelectricity in the late 19th and 20th centuries, heavy metallurgical and chemical industries were attracted to the major transverse valleys of France, southern Switzerland, and western Austria. Later, factories producing such consumer products as textiles (in the Rhine valley of Austria) and sporting goods (the Annecy area in France) were established. One result of this industrialization was the depopulation of the small villages in the lateral valleys, an occurrence that was partially stemmed by the emergence of the tourism boom after 1960. Many of the early industrial enterprises are no longer viable because of obsolescence, foreign competition, the high cost of transporting raw materials from coastal ports to interior valley locations, or—as is the case with the steel plant in Aosta—because indigenous raw materials have been exhausted. The remaining plants have had to modernize, rationalize, restructure, and develop new products in order to remain competitive in world markets.

Tourism. The most significant economic change for the Alps has been the development of mass tourism since World War II. Tourism in the Alps is a risky business: capital investment can be considerable, whereas the season in which to recoup expenditure is short and can be disrupted by economic difficulties in neighbouring countries or by a lack of snow in winter and cool, rainy weather in summer. Furthermore, there is fierce competition to attract tourists, not only among the different Alpine countries but also among the resorts within each country. There are some 600 ski resorts in the Alps, with more than 270 in Austria alone. Nevertheless, winter and summer tourism have injected enormous sums of money into the economies of the Alpine nations, a development that has been especially beneficial to the remote villages of the high lateral valleys. Employment opportunities in the service sector have increased substantially, taking up the slack caused by a decline in agricultural and industrial employment.

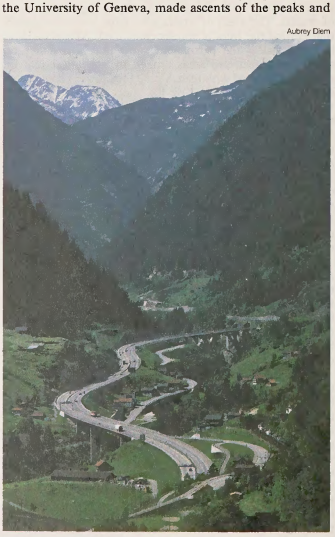
Transportation. The rugged and steep terrain of the Alps long was a barrier to transportation. Beginning in Celtic times, however, and continuing into the present, mountain passes have served as communication links between otherwise isolated valleys; the passes have evolved from simple paths to paved, multilane highways. Such settlements as Chur in eastern Switzerland, a focal point for the numerous passes in the region, have been inhabited for more than 5,000 years. Andermatt, in south central Switzerland, grew in a similar manner.

Role of mountain passes

The advent of rail and later road transportation and the accompanying improvements in road-building techniques have ended the isolation of most areas of the Alps. Tunnels—and road tunnels in particular—which allow huge numbers of people to pass under the great Alpine massifs at all times of the year, have had the greatest impact: by facilitating such a steady onslaught of motor vehicles and people, they not only have made possible the tremendous growth in tourism in the 20th century but also have become a major contributing factor in the degradation of the Alpine environment.

Study and exploration. Records of ascents of various peaks in the Alps date from at least as early as the 14th century, and, in the late 18th and the 19th centuries, the interest in this activity created a vogue for serious mountaineering that began in the Alps and spread throughout the world. Horace Bénédict de Saussure, a professor at the University of Geneva, made ascents of the peaks and

Aubrey Diem



Highway to St. Gotthard tunnel and pass, Wassen, Switz.



The Apennines mountain range.

encouraged others to do so in the 1780s, when he made the earliest scientific observations of the mountains. With the systematization of geology as a science in the second half of the 19th century, Alpine investigation made great advances. The first geologic maps indicated the main structural outlines of the mountain system, which revealed unusually complicated geologic phenomena that seemed to be the result of something more than a massive upheaval within the Earth. One explanation offered was the theory of nappes—enormous masses of rock apparently squeezed and thrust across long distances by internal pressures in the Earth, eventually overlying strata of more recent age and different origin. This theory has been reinforced by the hypothesis of continental drift, which posited the realignment of entire land and water areas during vast geologic eras. Today, however, the tendency is to suppose a vertical uplift of the crystalline rock and a sliding down (under the effects of both gravity and the relatively plastic nature of the layers of schists and marls) of the sedimentary cover, and a somewhat more complicated origin for the nappes.

Simultaneous with this conjecture on geologic regions, the subjects of Alpine relief, climatology, and vegetable, animal, and human geography also came in for observation and analysis. The Alps are probably the most thoroughly studied mountain system on Earth, particularly at such institutions as the universities of Grenoble, France, and Innsbruck, Austria, and the Swiss Federal Institute of Snow and Avalanche Research near Davos; yet they continue to present hosts of complex and evolving scientific problems. (P.V./A.Di.)

APENNINES

The Apennines (Italian: Appennino), a series of mountain ranges that are bordered by narrow coastlands, form the physical backbone of peninsular Italy. From Cadibona Pass in the northwest, close to the Maritime Alps, they form a great arc, which extends as far as the Egadi Islands to the west of Sicily. Their total length is approximately 870 miles (1,400 kilometres), and their width ranges from 25 to 125 miles. Mount Corno, 9,554 feet (2,912 metres), is the highest point of the Apennines proper on the peninsula. The range follows a northwest–southeast orientation as far as Calabria, located at the southern tip of Italy; the regional trend then changes direction, first toward the south and finally westward.

The Apennines are among the younger ranges of the Alpine system and, geologically speaking, are related to the coastal range of the Atlas Mountains of North Africa. Similarities have also been observed with the Dinaric Alps, which extend through the Balkan region, including Greece. Nearby Sardinia and Corsica, on the other hand, are dissimilar to the Apennines, their granitic rock masses being linked to outcroppings along the Spanish and French coast, from which they parted some 20 million years ago.

Physical features. *Geology.* The majority of geologic units of the Apennines are made up of marine sedimentary rocks that were deposited over the southern margin of the Tethys Sea, the large ocean that spread out between the Paleo-European and the Paleo-African plates during their separation in the Mesozoic era (about 245 to 66 million years ago). These rocks are mostly shales, sandstones, and limestones, while igneous rocks (such as the ophiolites of the northern Apennines, the remains of an older oceanic crust) are scarce. The oldest rocks—metamorphic units of the late Paleozoic era (about 300 to 245 million years ago), with their continental sedimentary cover containing plant remains—represent the relicts of the ancient continental crust of Gondwanaland and are found in small outcroppings. The granitic intrusions and metamorphic units of the Calabrian and Sicilian ranges are also Paleozoic (Hercynian orogeny), but they are believed to be Alpine in origin and only became part of the Apennine chain through subsequent major tectonic movements.

Apennine orogeny

The Apennine orogeny developed through several tectonic phases, mostly during the Cenozoic era (*i.e.*, since about 66 million years ago), and came to a climax in the Miocene and Pliocene epochs (23.7 to 1.6 million years ago). The Apennines consist of a thrust-belt structure with three basic trending motions: toward the Adriatic Sea (the northern and central ranges), the Ionian Sea (Calabrian Apennines), and Africa (Sicilian Range). During Plio-Pleistocene times, ingression and regression of the sea caused the formation of large marine and continental sedimentary belts (sands, clays, and conglomerates) along the slopes of the new chain. In the past million years numerous large faults have developed along the western side of the Apennines, which may be connected to the crustal thinning that began about 10 million years ago and resulted in the formation of a new sea, the Tyrrhenian. Most of these faults have also facilitated strong volcanic activity, and a volcanic chain has formed along them from Mount Amiata in Tuscany to Mount Etna in Sicily; most of these volcanoes—including Mount Amiata, Mount Cimino, the Alban Hills near Rome, and the Ponza Islands—are extinct, but, to the south, Mount Vesuvius, the Eolie Islands, and Mount Etna are all still active. Seismic activity is common along the entire length of the chain (including Sicily), with more than 40,000 recorded events since AD 1000. Mostly earthquakes are shallow (three to 19 miles deep), and their occurrence is probably connected to the settlement of the chain in the complicated interaction between the African and European tectonic plates.

The geologic youth of the Apennines, and a great variety of rock types, are responsible for the rugged appearance of the range today. In the north, in Liguria, sandstones, marls, and greenstones occur. Landslides often occur in these brittle rocks. In Tuscany, Emilia, Marche, and Umbria, clay, sand and limestones are common. In Lazio, Campania, Puglia, Calabria, and northern and eastern Sicily, there are large calcareous rock outcrops, separated by lowland areas of shale and sandstone. In Molise, Basilicata, and Sicily, extensive argillaceous (clayey) rock types occur. Here, the landscape has a thirsty and desolate appearance, with frequent erosion of the *calanchi*, or badlands, type.

Physiography. Starting from the north, the main subdivisions of the Apennines are the Tuscan-Emilian Apennines, with a maximum height of 7,103 feet at Mount Cimone; the Umbrian-Marchigian Apennines, with their maximum elevation (8,130 feet) at Mount Vettore; the Abruzzi Apennines, 9,554 feet at Mount Corno; the Campanian Apennines, 7,352 feet at Mount Meta; the Lucanian Apennines, 7,438 feet at Mount Pollino; the Calabrian Apennines, 6,414 feet at Mount Alto; and, finally, the Sicilian Range, 10,902 feet at Mount Etna. The ranges in Puglia (the "bootheel" of the peninsula) and southeastern Sicily are formed by low, horizontal limestone plateaus, which remained less affected by the Alpine orogeny.

The rivers of the Apennines have short courses. The two principal rivers are the Tiber (252 miles long), which follows a southerly course along the western base of the Umbrian-Marchigian range before flowing through Rome to the Tyrrhenian Sea, and the Arno (155 miles), which flows westerly from the Tuscan-Emilian range through Florence to the Ligurian Sea. In spite of the limited length of the rivers, the action of running water is the chief agent of erosion responsible for molding the contemporary Apennine landscape. The character of the physical geography depends on the varying nature of the rocks in each region and their resistance to water action. The overall aspect of relief, however, exhibits characteristics of an early, or juvenile, stage in the cycle of erosion. In limestone areas, karst erosion, with crevasses worn by water action, predominates. In the highest part of the Apennines there are traces of the erosive action of the glaciers of the last Ice Age, although, unlike the Alps, contemporary glaciers are lacking.

Landscape formed by erosion

Lakes—which today are small and scattered in distribution—were also much more abundant in earlier Quaternary times. The alluvial Lake Trasimeno (49 square miles [128 square kilometres]) in the Umbrian-Marchigian Apennines is the largest lake of the present range. Other natural lakes, of varying origin, are scattered throughout the range. There are more than 200 artificial lakes created for purposes of power and irrigation.

Climate. The climate of the highest section of the Apennines is continental (as found in the interior of Europe) but ameliorated by Mediterranean influences. Snowfalls are frequent, with cold winters and hot summers (average July temperature 75°–95° F [24°–35° C]). Average rainfall—at between 40 and 80 inches (1,000 and 2,000 millimetres) per year—is higher on the Tyrrhenian slopes than on the eastern, or Adriatic, side of the Apennines.

Plant and animal life. The flora of the Apennines is Mediterranean in type and varies with both latitude and altitude. In the north, woodlands with oak, beech, chestnut, and pine predominate. To the south, ilexes, bays, lentisks, myrtles, and oleander (a flowery evergreen herb) abound. Prevailing crops are represented by the olive trees, growing to a height of about 1,300 feet above sea level; citrus fruits, which are well developed in Calabria and Sicily; and grapes, which are found in abundance in Tuscany, Lazio, and Puglia. Other products of the range include sugar beets (in the plain of Emilia), potatoes, vegetables, and fruit. The importance of corn (maize) diminished with the depopulation of hill farms. In the highland areas, pasturing remains the main form of land utilization.

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Trucks carrying high-grade marble quarried in the Apennines near Carrara, Italy.

Apennine fauna has been little studied. In addition to typical Mediterranean fauna, many of the indigenous Apennine species (with several species found exclusively within the range, including some insects, the brown "marsicano" bear, the chamois, the wolf, and the wild boar) are now preserved in two natural reserves (Abruzzo National Park and Sila Park) and several regional parks.

The people and economy. Since prehistoric times the Apennines have been the home of Italic peoples. Today, the highest village settlement is found at about 4,500 to 5,000 feet above sea level, at the upper limit of cultivated land. More densely populated areas are found in the wide river valleys, which are rich in alluvial and cultivated land (*e.g.,* the valleys of Lunigiana in Liguria, Garfagnana in Tuscany, and those of the upper Arno and Tiber rivers). Internal basins (Foligno, Terni, Rieti, l'Aquila, Sulmona, Avezzano) are also well populated. Rural depopulation, resulting from the lack of development of the Italian south and the attraction of industrial areas in northern Italy and elsewhere in Europe, has reached major proportions. This emigration has nevertheless slackened, mainly as a result of attempts to develop the local economy.

Settlement patterns

In the foothills of the Apennines, manufacturing industries are widespread, while extraction industries have been developed in the adjacent coastal plain, often in association with important discoveries of natural gas. Such minerals as mercury, sulfur, boron, and potassic salts are also of significance, while the marble quarries—particularly those near Carrara—of the Apennines have been famous for centuries.

The Apennines are crossed by several railway lines, some of them double-tracked. There are numerous roads providing access to the range, although the rugged terrain makes for difficulties. Among the highways that have overcome the barriers of relief with imposing series of tunnels and embankments is the Autostrada del Sole ("Highway of the Sun"), which is the main artery of peninsular Italy and one of the great scenic routes of Europe.

Study and exploration. Various aspects of the Apennines—their geology, hydrography, zoology, and botany—have been studied by the leading Italian universities, the Italian Geological Survey, and such bodies as the National Research Council of Italy and the Hydrographic Service of the Ministry of Public Works. Since the late 1970s many scientists have organized several national research projects concerning the geologic evolution and hazards of the Apennines and have also conducted environmental evaluations and petroleum surveys. (B.A./Ma.P.)

CARPATHIAN MOUNTAINS

The Carpathian Mountains are a geologically young European mountain chain forming the eastward continuation of the Alps. From the Danube Gap, near Bratislava, Slovakia, they swing in a wide arc some 900 miles (1,450 kilometres) long to near Orşova, Romania, at the portion of the Danube River valley called the Iron Gate. These are the conventional boundaries of these arcuate ranges, although, in fact, certain structural units of the Carpathians extend southward across the Danube at both sites mentioned. The true geologic limits of the Carpathians are, in the west, the Vienna Basin and the structural hollow of the Leitha Gate in Austria and, to the south, the structural depression of the Timok River in Serbia and Montenegro. To the northwest, north, northeast, and south the geologic structures of the Carpathians are surrounded by the sub-Carpathian structural depression separating the range from other basic geologic elements of Europe, such as the old Bohemian Massif and the Russian, or East European, Platform. Within the arc formed by the Carpathians are found the depressed Pannonian Basin, composed of the Little and the Great Alfolds of Hungary, and also the relatively lower mountain-and-hill zone of Transdanubia, which separates these two plains. Thus defined, the Carpathians cover some 80,000 square miles (200,000 square kilometres).

Although a counterpart of the Alps, the Carpathians differ considerably from them. Their structure is less compact, and they are split up into a number of mountain blocks separated by basins. The highest peaks, Gerlachovský Štít (Gerlach) in the Carpathians (8,711 feet [2,655 metres]) and Mont Blanc in the Alps (15,771 feet), differ greatly in elevation, and on average the Carpathian mountain chains are also very much lower than those of the Alps. Structural elements also differ. The sandstone–shale band known as flysch, which flanks the northern margin of the Alps in a narrow strip, widens considerably in the Carpathians, forming the main component of their outer zone, whereas the limestone rocks that form a wide band in the Alps are of secondary importance in the Carpathians. On the other hand, crystalline and metamorphic (heat-altered) rocks, which represent powerfully developed chains in the central part of the Alps, appear in the Carpathians as isolated blocks of smaller size surrounded by depressed areas. In addition to these features, the Carpathians contain a rugged chain of volcanic rocks.

Similar differences can be observed in the relief of these two mountain systems, notably in the way that the processes of erosion have occurred. The relief forms of the Alps today result for the most part from the glaciations of the last Ice Age. These affected practically all mountain valleys and gave them their specific relief character. In the Carpathians, glaciation affected only the highest peaks, and the relief forms of today have been shaped by the action of running water.

Physical features. *Geology.* The Carpathians extend in a geologic system of parallel structural ranges. The Outer Carpathians—whose rocks are composed of flysch—run from near Vienna, through Moravia, along the Polish-Czech-Slovak frontier, and through western Ukraine into Romania, ending in an abrupt bend of the Carpathian arc north of Bucharest. In this segment of the mountains, a number of large structural units of nappe character (vast masses of rock thrust and folded over each other) may be distinguished. In the eastern part of the Outer Carpathians this fringe is formed by the Skole Nappe, and in the western part it is formed by the Silesian Nappe, both of which are split by the longitudinal central Carpathian depression. Overthrust on the Silesian Nappe is the Magura Nappe, the counterparts of which in the east are the Chornohora (Chernogora) and the Tarcău nappes.

Parallel structural ranges

The Inner Carpathians consist of a number of separate blocks. In the west lies the Central Slovakian Block; in the southeast lie the East Carpathian Block and the South Carpathian Block, including the Banat and the East Serbian Block. The isolated Bihor Massif, in the Apuseni Mountains of Romania, occupies the centre of the Carpathian arc. Among the formations building these blocks are ancient crystalline and metamorphic cores onto which younger sedimentary rocks—for the most part limestones and dolomites of the Mesozoic era (245 to 66.4 million years ago)—have been overthrust.

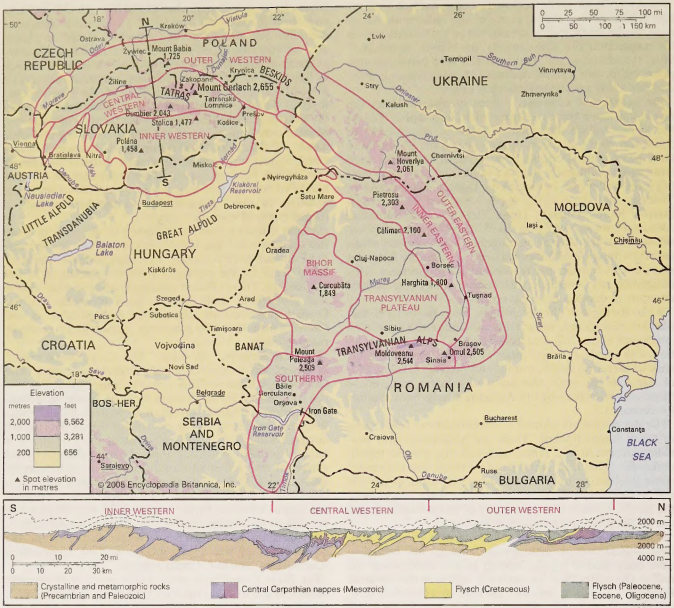
The third and innermost range is built of young Tertiary volcanic rocks formed less than 50 million years ago, differing in extent in the western and eastern sections of the Carpathians. In the former they extend in the shape of an arc enclosing, to the south and east, the Central Slovakian Block; in the latter they run in a practically straight line from northwest to southeast, following the line of a tectonic dislocation, or zone of shattering in the Earth's crust, parallel with this part of the mountains. Between this volcanic range and the South Carpathian Block, the Transylvanian Plateau spreads out, filled with loose rock formations of young Tertiary age.

The Central Slovakian Block is dismembered by a number of minor basins into separate mountain groups built of older rocks, whereas the basins have been filled with younger Tertiary rocks.

In Romania, orogenic, or mountain-building, movements took place along the outer flank of the Carpathians until late in the Tertiary period (less than 10 million years ago), producing foldings and upheaval of the sedimentary rocks of the sub-Carpathian depression; the result was the formation of a relatively lower range called the sub-Carpathians adjoining the true Carpathians.

The relief forms of the Carpathians have, in the main, developed during young Tertiary times. In the Inner Carpathians, where the folding movements ended in the Late Cretaceous epoch (97.5 to 66.4 million years ago),

Relief forms



Regional division of the Carpathian Mountains and a geologic cross section of the Western Carpathians. The location of the cross section is shown by the line N–S on the map.

local traces of older Tertiary landforms have survived. Later orogenic movements repeatedly heaved up this folded mountain chain, leaving a legacy of fragmentary flat-topped relief forms situated at different altitudes and deeply incised gap valleys, which often dissect the mountain ranges. In this way, for example, the gap sections of the Danube and of some of its tributaries—the Váh, the Hernád, and the Olt—developed.

The last Ice Age affected only the highest parts of the Carpathians, and glaciers were never more than about 10 miles long, even in the Tatras, where the line of permanent snow ran at 5,500 feet above sea level.

Harrison Forman



Deep river-cut gorge in the Carpathian Mountains of Romania.

Physiography. Generally speaking, the Carpathians have been divided into the Western and the Eastern Carpathians, the latter also called—probably more accurately—the Southeastern Carpathians. The extent of these two regions and their subdivisions is given in Table 1. There are marked differences between these parts. The Western Carpathians show a clearly marked zoning in geologic structure and relief forms, and the highest elevations occur in the central part of this province, in the Tatras and the Lower Tatras ranges. The geologic structure of the inner part of the Western Carpathians is marked by a break running from the east and the south along a line of dislocation in the Earth's crust. Along this line, masses of volcanic rocks have been piled up surrounding the Central Western Carpathian Block in a wide arc, with its convex side turned eastward. The boundary between the Western and the Southeastern Carpathians occurs at the narrowest part of the mountain range, marked by the valley of the San River to the north and the Łupków Pass (2,100 feet) and the Laborec Valley to the south. There the Carpathians are only some 75–80 miles wide, while in the west they are 170 miles and in the east as much as 220–250 miles across.

Geologic structure and relief forms

The Southeastern Carpathians are formed by a triangular block of mountains surrounding a basin. The three mountain formations concerned differ in origin and structure. The Eastern Carpathians, running in a northwest–southeast direction, include the flysch band, which represents the continuation of the Outer Western Carpathians, and also an inner band of crystalline and volcanic rocks. In

Table 1: Subdivisions of the Carpathians

	approximate area	
	sq km	sq mi
Western Carpathians	68,000	26,000
Outer Western Carpathians	27,500	10,500
Central Western Carpathians	15,500	6,000
Inner Western Carpathians	25,000	9,500
Southeastern Carpathians	131,000	50,500
Outer Eastern Carpathians	35,500	13,500
Inner Eastern Carpathians	21,250	8,000
Southern Carpathians	28,250	11,000
Transylvanian Plateau	28,500	11,000
Bihor Massif (Apuseni Mountains)	17,500	7,000

contrast, the Southern Carpathians, running east-northeast to west-southwest, consist, in the main, of metamorphic rocks. The Bihor Massif is also of metamorphic rock but is covered with younger sediments.

The Outer Western Carpathians are generally of low elevation; the highest point is Mount Babia (5,659 feet) in the Beskid Range, straddling the borders of Poland, the Czech Republic, and Slovakia. On the Polish side, a national park has been established. A considerable part of the Outer Western Carpathians lacks a truly mountainous landscape and rather resembles a hilly plateau elevated to 1,300–1,600 feet above sea level.

The Central Western Carpathians consist of a series of isolated mountain ranges separated by structural depressions. Highest among them are the Tatras (Mount Gerlach, 8,711 feet), exhibiting a typical high-mountain glacial relief with ice-scoured (cirque) lakes and waterfalls. This highest Carpathian massif is built of crystalline (granite) and metamorphic rocks, but the northern part contains, upthrust from the south, several series of limestone rocks with associated karst, or water-incised, relief forms. On both the Polish and Slovakian sides, national parks have been established. South of the Tatras, separated by the Liptov and Spiš basins, run the parallel Lower Tatras, similar in geologic structure but lower (Ďumbier Peak, 6,703 feet) and with a less conspicuous glacial relief. Along the boundary line between the Outer and the Central Western Carpathians extends a narrow strip of klippen (limestone) rocks, which, north of the Tatras, has developed into the small but picturesque Pieniny mountain group. A narrow and sharply winding gap valley has been incised there by the Dunajec River, a tributary of the Vistula.

The Tatras

The Inner Western Carpathians are lower and more broken. The principal mountain groups are the Slovak Ore Mountains (Slovenské Rudohorie), with Stolica (4,846 feet) as the highest peak; they are built of metamorphic rocks and of sedimentaries of the Paleozoic era more than 250 million years old. Also found there are tableland areas of Mesozoic limestones, about 150 million years old, containing such large caves as the Domica-Aggtelek Cave on the Slovak-Hungarian boundary, which is 13 miles long. Mountain groups of volcanic origin are important in this part of the Carpathians; the largest among them is Pol'ana (4,784 feet).

Compared with the Outer Western Carpathians, the Outer Eastern Carpathians, which are their continuation, are higher and show a more compact banded structure. The highest mountain group is the Chernohora (Chernogora) on the Ukrainian side, with Hoverlya (6,762 feet) as the highest peak. The Inner Eastern Carpathians attain their highest altitude in the Rodna (Rodnei) Massif in Romania; they are built of crystalline rocks and reach a peak in Pietrosu (7,556 feet). To the south, extinct volcanoes in the Căliman and Harghita ranges have, to some extent, kept their original conical shape; the highest peaks of these ranges are 6,890 feet and 5,906 feet, respectively. Fringing the true Eastern Carpathians runs a narrow zone called the sub-Carpathians, which is made up of folded young Tertiary rocks superimposed on the sub-Carpathian structural depression.

The Southern Carpathians culminate in the Făgăraş Mountains (highest point Moldoveanu, 8,347 feet), which show Alpine-type relief forms. The western part of the Southern Carpathians—that is, the Banat Mountains and the mountains of eastern Serbia (which, at the Iron Gate, are split apart by the gap valley of the Danube)—does not exceed an altitude of 5,000 feet.

The Bihor Massif, which occupies an isolated position inside the Carpathian arc, features widespread flat summit plains bordered by narrow, deep-cut valleys. The highest peak is Curcubăta (6,067 feet).

Finally, mention should be made of the Transylvanian Plateau. This is made up of poorly resistant young Tertiary rocks and characterized by a forestless hilly landscape with elevations of 1,500 to 2,300 feet above sea level; the valleys are cut to depths of 325 and 650 feet.

Drainage. The water runoff from the Carpathians escapes for the most part (about 90 percent) into the Black Sea. The great curve of the mountain chain abuts in the south upon the Danube; in the east it is flanked by a tributary of the Danube, the Prut River, and farther on by the Dniester River, which flows to the Black Sea. Only the northern slope of the Carpathians, mostly in Poland but partly in Slovakia, is linked to the Baltic Sea by the drainage basins of the Vistula and (in part) Oder rivers. Larger rivers originating in the Carpathians include the Vistula and the Dniester and the following Danube tributaries: Váh, Tisza, Olt, Siret, Prut. The Carpathian rivers are characterized by a rain–snow regime; high-water periods occur in the spring (March–April) and in summer (June–July), with the latter usually more powerful. Often these floods assume catastrophic dimensions caused by poor ground retention of the rainfall. There has long been an urgent need for the construction of storage basins, work on which was initiated on a large scale in the decades following World War II. The largest storage basin is in the Danube River valley on the frontier between Romania and Serbia and Montenegro. Other large basins include one in the Bistriţa valley in Romania, one in the San valley in Poland, and one in the Orava valley in Slovakia. Altogether there are some 50 storage basins in the Carpathians. Natural mountain lakes are relatively rare, and all of them are small. Although there are some 450 lakes, their total surface is barely 1.5 square miles. The high-mountain lakes are mainly of glacial origin.

Flood peril

Climate. The situation of the Carpathians, on the boundary line between western and eastern Europe, is reflected in the features of their climate, which in winter is governed by the inflow of polar-continental air masses arriving from the east and northeast, while during other seasons oceanic air masses from the west predominate. The distance from the Atlantic Ocean (from 620 to 1,240 miles) and the influence of the intervening masses of the Alps and the Bohemian Massif cause diminished precipitation in the Carpathians. The Carpathians thus possess certain features of a continental climate, although from the viewpoint of relief they constitute a sort of island amid the surrounding plains, where the climate is much drier. The continentality of the climate is clearly seen in the intermontane depressions, however, as well as on the lower parts of the southern mountain slopes. In winter, temperature inversion, in which the low depressions retain very cold air while the mountaintops show relatively high temperatures, is a common occurrence throughout the Carpathians. In some depressed areas, notably the Transylvanian Plateau, the total annual precipitation is less than 24 inches (600 millimetres), while precipitation in the mountains at 2,600 feet (800 metres) above sea

Table 2: Climatic Stages of the Western Carpathians

type	stage	mean annual temperature		average altitude limits (above sea level)*	
		degrees Fahrenheit	degrees Celsius	feet	metres
Nival	cold	25	−4	8,710	2,655
Nival-pluvial	temperate cold	28	−2	6,070	1,850 (1,670)
	very cool	32	0	5,080	1,550 (1,400)
	cool	36	2	3,600	1,100
Pluvial-nival	temperate cool	39	4	2,300	700
	temperate warm	43	6	820	250
	mountain foreland	46	8	under 820	under 250

*The figures in parentheses refer to the Outer Carpathians.

Table 3: Vegetation Stages of the Carpathians
(feet [metres])

stages	Western Carpathians		Eastern Carpathians	Southern Carpathians
	Outer	Inner		
Nival	—	up to 8,710 (2,655)	—	—
Alpine	up to 5,660 (1,725)	up to 7,200 (2,200)	up to 6,600 (2,000)	up to 8,344 (2,544)
Subalpine	up to 5,480 (1,670)	up to 5,900 (1,800)	up to 6,070 (1,850)	up to 7,200 (2,200)
Upper forest	up to 4,600 (1,400)	up to 5,080 (1,550)	up to 5,080 (1,550)	up to 5,900 (1,800)
Lower forest	up to 3,770 (1,150)	up to 4,100 (1,250)	up to 4,100 (1,250)	up to 4,900 (1,500)
Foreland	up to 1,800 (550)	up to 2,300 (700)	up to 2,000 (600)	up to 2,800 (850)

level is about 45 inches, and on the highest massifs it reaches 65 to 70 inches. The mean annual and monthly air temperatures vary according to altitude above sea level but by no means at constant rates.

For the Polish part of the Carpathians, a series of climatic types and stages has been distinguished; and with slight modification these may be applied to the whole Carpathian mountain range.

Plant and animal life. Different vegetation stages may also be distinguished for the various altitudinal zones of the Carpathians. The alpine stage is characterized by high mountain pastures, the subalpine stage by dwarf pine growth, the upper forest stage by spruce, and the lower forest stage by beech. The foreland stage is noted for oaks and elms. The natural vegetation stages are matched by stages of economic land use: the foreland by wheat and potato growing, the lower forest stage by oats and potato growing (up to 3,280 feet), and the upper forest stage and the subalpine stages by pastoral use.

The plant life of the Carpathians contains many unique species, especially in the southeastern part of the mountains where the effect of Quaternary climatic cooling was less marked. Forests have been best preserved in the eastern part of the Carpathians, and there the animal life includes bears, wolves, lynx, deer, boars, and, in the highest parts (in the Tatras), chamois and marmots.

The people. The distribution of the population in the Carpathians depends on natural land features and on socioeconomic conditions; hence it is very much diversified. In the valleys between the mountains and again on the northern slopes of the Western Carpathians, the population density is heavy, whereas, close by, practically uninhabited mountain massifs are to be found. On the whole, the Southeastern Carpathians are less densely settled than the Western Carpathians, but there also marked aggregations of people occur in the valleys.

Nationalities

The western slope of the Western Carpathians is inhabited by Czechs, the northern slope by Poles, the entire central part of the Western Carpathians by Slovaks, and the southern portion by Hungarians. The northern part of the Eastern Carpathians, both its outer and inner sectors, is occupied by Ukrainians; but south of latitude 47° a Romanian population predominates. Inside the arc of the Eastern Carpathians and also partly on the Transylvanian Plateau lives a compact island of Hungarian population and some remnants of German colonists dating from the Middle Ages. Finally, the southwestern margin of the Carpathians, beyond the Danube gap, is occupied by Serbs. Generally speaking, the greater part of the Western Carpathians and the northern part of the Eastern Carpathians is inhabited by a Slav population, and the southern part of both these Carpathian provinces, with the exception of the mountains of eastern Serbia, by Romanians and Hungarians.

In the 13th and 14th centuries Romanian shepherds, wandering with their flocks, moved along the Carpathians into what is today Ukrainian, Slovakian, and Polish territory, and traces of this penetration have survived in geographic nomenclature and in economic methods and also in types of buildings, garments, and customs, although by the second half of the 20th century many of the latter were gradually disappearing. In general outlines, but by no means in detail, the diversity in nationality coincides with today's pattern of the political boundaries.

The economy. *Agriculture and industry.* The Carpathians are a region of agriculture and forestry, with industry in an early stage of development. Agriculture flourishes on the Transylvanian Plateau, in intramontane basins, and on lower parts of the mountains, up to some 3,000 feet elevation. On the northern slopes wheat, rye, oats, and potatoes predominate; on the southern slopes corn (maize), sugar beets, grapes, and tobacco are grown. Above 3,000 feet elevation forestry and pastoral life are the rule. Natural gas, found mainly on the Transylvanian Plateau, is important among natural resources. Oil is also significant; the richest deposits lie in the Romanian sub-Carpathians. Brown coal is found in low-lying areas of the Western Carpathians in the Czech Republic, Slovakia, and Hungary, and some bituminous coal is mined in the Romanian Southern Carpathians. Also noteworthy are the rock salt beds of the Transylvanian Plateau, the Romanian sub-Carpathians, and the base of the Polish Carpathians and the potassium salts found at the base of the Ukrainian Carpathians. Iron ores, ores of noniron metals, and gold and silver ores were intensively mined in the Middle Ages in the Bihor Massif and in the Slovakian Western Carpathians, but today all these deposits are of minor importance.

Economic development

Larger industrial centres are Bratislava, the capital of Slovakia, with a thriving machinery and a petrochemical industry; and Košice, the principal town of eastern Slovakia, with a modern steel mill. Prominent in Romania are Cluj-Napoca, which is the principal town of the Transylvanian Plateau, concentrating on machinery making and chemical and food products; Braşov, situated in a basin near the boundary between the Western and Southern Carpathians, a town where machine production predominates; and Sibiu, lying between the Transylvanian Plateau and the Southern Carpathians.

Tourism. The Carpathians are a popular tourist and recreation venue, especially for the people of Poland, Hungary, Romania, the Czech Republic, and Slovkia. Tourist travel from other countries is less developed, although a number of areas attract visitors from abroad. Most important among these is Zakopane, a centre of sports activities, tourism, and recreation, situated in Poland north of the Tatras. On the Slovak side of the Tatras, a similar role is played by a number of localities, notably Tatranská Lomnica, Smokovec, and Štrbské Pleso. In Romania the outstanding centre for winter sports and tourism is Sinaia, situated in the Prahova valley. The Carpathians are noted for their abundance of mineral springs. Among the best-known Carpathian health spas are Krynica in Poland, Piešťany in Slovakia, and Borsec, Băile Herculane, and Tuşnad in Romania.

Transportation. The railway network of the Carpathians came into existence in the latter half of the 19th century and the beginning of the 20th, at a time when most of the mountains were in Austria-Hungary. In this period the nodal point was Budapest, situated in the centre of the Carpathian arc. The principal railway lines were laid out radially from Budapest across the various mountain passes and were tied in with the main longitudinal west–east trunk line running in an arc along the northern flank of the Carpathians between Vienna and Chernovtsy, Ukraine (then situated in Austria-Hungary). This northern trunk continued as the sub-Carpathian Romanian railway line running toward Bucharest and, farther on, to Orşova, which, in turn, was linked by a Hungarian railway section with Budapest and thus with Vienna. After the Austro-Hungarian Empire had collapsed, this system lost much of its economic and strategic importance. Within its boundaries the new state of Czechoslovakia started to build

The historical legacy

longitudinal west–east railway lines. For Romania, which had been allotted Carpathian Transylvania, the previously neglected lines became highly important. To some extent, this pattern changed after World War II, when the northern part of the Eastern Carpathians and Trans-Carpathian Ukraine became part of what was, until 1991, the Soviet Union. The railway lines crossing this part of the Carpathians became arteries that now link Ukraine, Slovakia, and Hungary. Although the lines between Poland and Slovakia lost most of their importance in passenger and freight transport, truck routes utilizing the Dukla (1,640 feet), Jablonkov, and other passes became significant in freight traffic between Poland and the countries south of the Carpathians. The most important Carpathian railway lines have been electrified, although the Budapest–Vienna line was electrified before World War II.

Study and exploration. Many nationalities are in contact with one another in the Carpathians, and this diversity has effected the development of scientific research in the region. From the end of the 18th century until World War I, most of the Carpathians were within the boundaries of Austria-Hungary, and throughout this period the Carpathians were readily accessible to all scientists of this multinational empire; the work of Polish scientists, together with that of Germans and Hungarians, is considered most noteworthy. In the late 19th century the Austrian general staff published the first comprehensive topographic map of the region. A century later, each of the countries whose territory covered part of the Carpathians—the Czech Republic, Slovakia, Poland, Romania, Hungary, and Ukraine—had topographic maps drawn to a scale of 1:50,000 and 1:200,000—compiled on the basis of a coordinated geodetic system and in a mutually correlated sheet pattern.

Mapping

As for geologic maps, the first paper dealing with the geology of the Carpathians as a whole was published in 1815. Today each of the Carpathian countries has its own general geologic maps, and there is also abundant regional geologic literature. In 1922 the International Geological Congress created an association of Carpathian geologists, which met every three years thereafter. Regional research in physical geography is also well advanced, and in 1963 a geomorphologic committee for the Carpathians and the Balkans was established.

Research is somewhat less advanced in climatology and biogeography, although a number of papers began to appear in the second half of the 20th century. In human geography much attention has been given to the problems of pastoral life and associated population movements. No synthetic survey of the economic geography of the whole Carpathians has appeared, because economic problems have been studied separately in each of the countries involved. Indeed, the first comprehensive geographic account of the Carpathians as a whole, by the Polish geographer Antoni Rehman, was not published until 1895.

Since World War II the Carpathians have become the object of research by a number of scientific centres in the countries involved, with the geographic institutes of the several national academies of sciences and the geographic and natural history institutes of various universities playing a leading role. National geologic institutes and institutes of hydrology and meteorology have also amassed a considerable body of information. (J.A.K.)

EUROPEAN PLAIN

One of the greatest uninterrupted expanses of plain on the Earth's surface sweeps from the Pyrenees Mountains on the French-Spanish border across northern Europe to the Ural Mountains in Russia. In western Europe the plain is comparatively narrow, rarely exceeding 200 miles (320 kilometres) in width, but as it stretches eastward it broadens steadily until it reaches its greatest width in western Russia, where it extends more than 2,000 miles.

Because it covers so much territory, the plain gives Europe the lowest average elevation of any continent. The flatness of this enormous lowland, however, is broken by hills, particularly in the west.

Physical features. *Physiography.* The western and central European section of the plain covers all of western and northern France, Belgium, The Netherlands, southern Scandinavia, northern Germany, and nearly all of Poland; from northern France and Belgium eastward it commonly is called the North European Plain. In the east the plain generally is called the East European, or Russian, Plain.

The North European Plain

Conditions in the North European Plain are complex in detail. The terrain is flat or gently undulating. Most of the area was glaciated several times during the Pleistocene epoch (1,600,000 to 10,000 years ago), and the landscape is typically postglacial. Drainage is poorly developed, glacial deposits called moraine blanket much of the area, and large sections are underlain by glacial outwash plains. Hilly terminal moraines, marking the stationary edges of the Pleistocene ice sheets, are strewn in great arcs across northern Germany and Poland and into Belarus (Belorussia) and western Russia. Interspersed with these moraines are long parallel spillways where glacial meltwaters flowed to the sea parallel to the ice front. These spillways were covered with sand and gravel by the rushing glacial streams. Today they are occupied by flat, poorly drained wetlands that are relatively unproductive. Sandy duneland borders the North and Baltic seas, and extensive windblown loess deposits, resulting from the intense wind erosion of the barren interglacial and postglacial landscapes, stretch across the North European Plain from France to western Russia.

Other landforms in the North European Plain include the extensive delta plain of The Netherlands that is formed by the deposits of the Rhine River as it enters the North Sea. Like many other delta plains, this area has rich and fertile soils and a flat terrain that is favourable for agriculture where it is properly drained. The Rhine has historically provided excellent transportation, and the region is one of the most densely populated areas in the world.

The East European Plain

Extending from eastern Poland to the Urals, the East European Plain encompasses all of the Baltic states and Belarus, nearly all of Ukraine, and much of the European portion of Russia and reaches north into Finland. Finland in the northwest is underlain by ancient, resistant, crystalline rocks, part of the Precambrian Baltic Shield. Because it was near the origin of the Pleistocene ice sheets that advanced southward over continental Europe, Finland's landscape is characterized more by glacial erosion than by glacial deposition. With its numerous lakes and swamps caused by the disarranged and immature drainage pattern, together with its thin soils and coniferous forests, the Finnish plain is similar in character and appearance to northern and eastern Canada, another heavily glaciated Precambrian Shield area. The continental glaciers that planed, eroded, and polished the rock surfaces in Finland deposited part of the material over the plains to the south.

The remainder of the East European Plain is deeply underlain by a relatively rigid platform of ancient rocks. At various times in its history, however, this area has slipped beneath the sea and been covered with sedimentary rocks. These rocks have been mildly bent and warped, but nowhere have they been sharply deformed. Consequently, the whole area from the Black Sea to the Arctic is one uninterrupted plain, everywhere below 1,500 feet (450 metres) in elevation.

Climate. The climate on the whole is characterized by marked seasonal changes, with cold winters and warm summers. The west has a maritime climate very favourable to agriculture. It has enough rain in all seasons to keep fields green. Summers are warm but not hot, and winters are cold but not freezing. As one moves eastward, the ameliorating maritime influence diminishes, and the character of the climate becomes more continental: rainfall is concentrated in the warmer months, summers are hotter, and winters become extremely cold. Spring and fall nearly disappear as separate seasons, and the greenness of the summer gives way abruptly each year to the gray drabness of a frozen winter. Agriculture in eastern Europe tends to be more difficult and less productive than in the west.

Drainage. The Garonne and the Loire rivers, with their numerous tributaries, drain much of western France before they enter the Bay of Biscay, and the Seine crosses the broad synclinal lowland of the Paris Basin on its way to the English Channel. The Schelde (Scheldt) and its



Rolling expanse of the European Plain, consisting of glacial deposits, in southern Poland.
D.C. Williamson

affluents (Lys, Scarpe, Dender, Demer) drain the Plain of Flanders and the low plateaus of central Belgium. The Meuse (Maas) pursues a varied course through the scarp lands of Lorraine, crosses the Ardennes in a valley cut transversely to the structure, turns at right angles along the coal furrow of southern Belgium, and then in a sweeping curve flows across the plain of the southern Netherlands to form a joint floodplain with the lower Rhine.

The Rhine is the main river of west central Europe, 865 miles in length, crossing the various structural and relief zones from its Alpine sources and entering its plain course in the North Sea lowlands. Farther east the several broadly parallel systems include the Weser, the Elbe, the Oder, and the Vistula, which rise in the uplands of central Europe and flow in a general northwesterly direction across the lowlands to the North or Baltic Sea. Each of these rivers reveals distinct right-angle bends, the result of the Pleistocene ice sheets, the margins and terminal moraines of which lay along an east–west line so that meltwaters escaping to the sea had to flow in a westerly direction, eroding broad intermorainal channels (*Urstromtäler*). When the ice sheets withdrew, the rivers occupied some sections of the east–west meltwater channels between their northerly courses. During the 19th and early 20th centuries several of these channels were used as routes to construct canals linking the north-flowing rivers. The Mittelland Canal of north central Germany is the most prominent of these.

Plant and animal life. Deciduous and coniferous forests diversify the landscape of the North European Plain, although present forests are no more than remnants of a thick mixed forest of oak, elm, ash, linden, and maple, which, since the Middle Ages, has given way to villages and fields in most places. The East European Plain, despite its great uniformity in terrain, exhibits strong regional contrasts in vegetation. Climatic differences produce great belts of characteristic plant life extending approximately east to west across the country. The southern part of the plain is an area of semiarid grasslands, which grade toward the north into more humid lands with taller grasses and rich, fertile soils. North of the grasslands lies a belt of hardwood forests; in the severely cold north lies a belt of coniferous forests and, bordering the Arctic Ocean, a belt of tundra.

Forest remnants

The wild animals of the plain are those characteristic of the whole of Europe, but their numbers have been considerably reduced and their habitats modified by intense human settlement of most areas of the plain.

The people. A variety of languages is spoken on the plain. As in the rest of Europe, almost all belong to the Indo-European family. The primary exceptions are the Finno-Ugric languages Hungarian and Finnish. Three major branches of Indo-European speech are represented. The Germanic branch is represented by Dutch, Flemish (in part of Belgium), German (including the dialect of Austria), Danish, and Swedish. The major representative of the Romance branch is French, along with Romanian spoken by some inhabitants of the East European Plain. In most of the east, however, people speak languages of the Slavic branch, of which Polish, Russian, Belorussian (White Russian), and Ukrainian are the most widespread but which also include Czech, Slovak, Slovene, Serbo-Croatian, and Bulgarian.

The European Plain includes people as diverse in culture as the French, Russians, Hungarians, and Swedes. In spite of cultural differences, many of these peoples traditionally shared underlying similarities that derived in part from a common pattern of village life and agricultural routine. Although the eastern part of the plain has remained traditional in many ways, the western part has been transformed as urban centres and industrialization have expanded into the surrounding countryside. Modern transportation has made it easy for farmers to get to town regularly. In many places, members of farming families, released from working on the land by the efficiency of modern machinery, have jobs in town but continue to live on the farm. Conversely, urbanites find that they can live in villages and work in town. Where this has occurred, the centuries-old distinction between urban and rural cultures (or subcultures) has been obliterated; even where developments have not gone that far, to the extent that the farmer is no longer parochial, the old distinction has been broken down. (R.T.A./Ed.)

The economy. The European Plain has long been a region of major agricultural importance, and, apart from the relatively small area occupied by its cities and towns today, the landscape—especially in the east—remains predominantly agricultural. Since the mid-19th century, however, the plain has also been one of the world's major heavy industrial regions. This has been especially true in the west, where the industrial concentration extending from Germany's Ruhr valley north along the Rhine River and west into The Netherlands, Belgium, and northern France has become Europe's most important centre of coal, steel, and chemical production. Similar industrial concentrations have grown up around smaller coalfields farther east, notably in Germany's Westphalia and Poland's Upper Silesia regions and in the Donets coalfield of Ukraine and Russia. The increasing importance of bulky imported raw materials to Europe's economy since the end of World War II has made large seaports such as Hamburg and Rotterdam major centres of industry and commerce as well.

Heavy industry

History. Parts of the European Plain harboured hunter-gatherer groups through much of the late Pleistocene, but significant settlement on the plain did not begin until postglacial times. Immigrants from the south moved north after the glaciers retreated and settled in widely scattered areas along the seacoasts, rivers, and lakeshores of the then heavily wooded plain. Until about 3000 BC—when agriculture became widespread in northern Europe—hunting, fishing, and foraging with stone and bone tools was the characteristic mode of life on the plain.

The first agricultural settlements were made primarily on lightly wooded sites with porous, easily worked, and well-drained soils—*i.e.*, those most suited to the fragile wooden

tools of the time. Such areas were found on the loess belt of the northern plain, which became the principal region of prehistoric settlement north of the Alps. Settlement on the thickly forested clay soils of the lowlands did not become feasible until the 8th century AD, with the invention of the heavy-wheeled plow. One of the most significant technological inventions of the Middle Ages, the heavy-wheeled plow opened the European Plain to settlement as never before and was soon followed by other improvements in agrarian technology.

The traditional two-field system of crop rotation, in which half the agricultural land was left fallow each year to maintain soil fertility, gave way to the more sophisticated three-field system: in addition to the usual sowing of wheat, barley, or rye in the autumn, another part of the land was planted in oats or nitrogen-fixing legumes (peas and beans) in the spring, and only the remaining third of the land was left fallow. The cultivation of a surplus of oats from the spring planting, moreover, provided feed that made possible the substitution of the swifter-gaited horse for plowing in place of the oxen. The ever-larger agricultural surpluses resulting from these advances led to the establishment of towns—and eventually cities—on the European Plain.

The Industrial Revolution

The character of the European Plain, however, remained primarily rural and agricultural until the 19th century, when the Industrial Revolution spread from England onto the Continent. Major coalfields stretching along the North European Plain from the Franco-Belgian border to the Donets Basin in Ukraine and Russia became focal points for the development of heavy industry. The plain's excellent system of rivers and canals furnished a network for the transport of such bulk cargo as coal and iron ore, and, when faster bulk transport later became necessary, its flat terrain enabled the unhindered construction of an extensive rail system. (Ed.)

PYRENEES

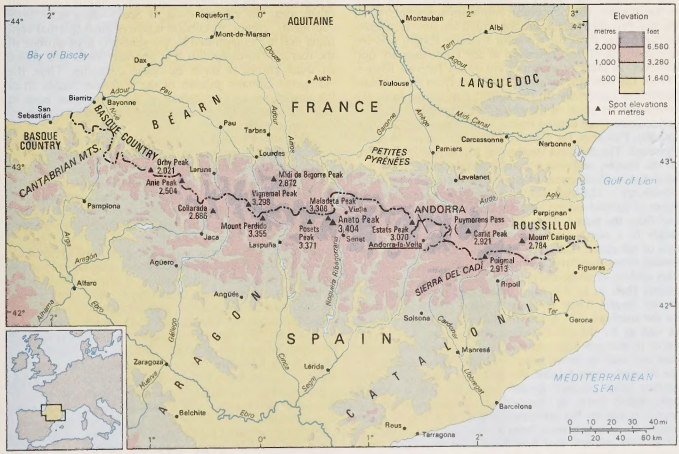
A mountain chain stretching from the shores of the Mediterranean Sea on the east to the Bay of Biscay on the Atlantic Ocean on the west, the Pyrenees (French: Pyrénées; Spanish: Pirineos) form a high wall between France and Spain that has played a significant role in the history of both countries and of Europe as a whole. The range is some 270 miles (430 kilometres) long; it is barely six miles wide at its eastern end, but at its centre it reaches some 80 miles in width. At its western end it blends imperceptibly into the Cantabrian Mountains along the northern coast of the Iberian Peninsula. Except in a few places, where Spanish territory juts northward or French southward, the crest of the chain marks the boundary between the two countries, though the tiny, autonomous principality of Andorra lies among its peaks. The highest point is Aneto Peak, at 11,169 feet (3,404 metres), in the Maladeta (Spanish: "Accursed") massif of the Central Pyrenees.

Cultural barrier

The Pyrenees long have been a formidable land barrier between Spain and Portugal on the Iberian Peninsula and the rest of Europe; as a consequence, these two countries traditionally have developed stronger associations with Africa than with the rest of Europe, and they have become tied to the sea. From Carlit Peak (9,584 feet) near the eastern limit of the Pyrenees to the peaks of Orhy and Anie, a succession of mountains rise nearly 9,800 feet; at only a few places, all well to the west, can the chain be crossed through passes lower than 6,500 feet. In both the lower eastern and northwestern sectors, rivers dissect the landscape into numerous small basins. The range is flanked on both sides by broad depressions—the Aquitaine and Languedoc to the north and the Ebro to the south—both receiving waters from the major rivers flowing out of the mountains, the Garonne of France and the major tributaries of the Ebro of Spain.

Physical features. *Geology.* The Pyrenees represent the geologic renewal of an old mountain chain rather than a more recent and vigorous mountain-building process that characterizes the Alps. Some 500 million years ago the region now occupied by the Pyrenees was covered with the folded mountains created during the Paleozoic era, called the Hercynian, of which the Massif Central in France and the Meseta Central in Spain are but two remnants. Although these other massifs have had a comparatively quiet history of internal deformation, or tectonism, since their emergence, the Pyrenean block was submerged in a relatively unstable area of the Earth's crust that became active about 225 million years ago.

The earliest formations, which were sediments severely folded over a granitic base, were submerged and covered by secondary sediments. They later were lifted once again into two parallel chains running to the north and south of the original Hercynian massif. These became the two


AQUITAINE
LANGUEDOC
FRANCE
BÉARN
BASQUE COUNTRY
BASQUE COUNTRY
PETITES PYRÉNÉES
ANDORRA
ROUSSILLON
CATALONIA
SPAIN
ARAGON
CANTABRIAN MTS.
SIERRA DEL CADI
Bay of Biscay
Gulf of Lion
MEDITERRANEAN SEA
Elevation
metres
feet
2,000 6,560
1,000 3,280
500 1,640
Spot elevations in metres
Roquefort
Mont-de-Marsan
Dax
Auch
Toulouse
Montauban
Albi
Bayonne
San Sebastián
Biarritz
Pau
Tarbes
Lourdes
Carcassonne
Narbonne
Pamiers
Lavelanet
Perpignan
Pyrenees Pass
Mount Canigou 2,784
Figueras
Ripoll
Gerona
Manresa
Barcelona
Tarragona
Reus
Lérida
Zaragoza
Huesca
Jaca
Aquero
Altsero
Angüés
Solsona
Aspe Pass
Somport Pass
Canfranc
Somport
Somport Peak 3,371
Mount Perdido 3,355
Collarada 2,888
Anie Peak 2,504
Orhy Peak 2,021
Laruns
Midi de Bigorre Peak 2,872
Vignemal Peak 3,298
Maladeta Peak 3,308
Vielha
Aneto Peak 3,404
Estats Peak 3,070
Andorra la Vella
Puigmal 2,913
Pamplona
Larrune
Larrau
Aspe
Ossau
Aragón
Ara
Gállego
Cinca
Segre
Noguera Ribagorçana
Noguera Pallaresa
Ter
Llobregat
Ebro
Aude
Agly
Têt
Orb
Hérault
Garonne
Adour
Gave de Pau
Gave d'Oloron
Gave d'Aspe
Gave de Pau
Gave de Gavarnie
Gave de Cauterets
Gave d'Azun
Gave de Barèges
Gave de Pau
Arros
Neste
Ariège
Salat
Aude
Tech
Têt
Agly
Orb
Hérault
Lez
Vidourle
Gardon
Rhône
Durance
Var
Argens
Siagne
Loup
Paillon
Roya
Nervia
Impéria
Centa
Arroscia
Tanaro
Po
Ticino
Adda
Oglio
Mincio
Adige
Brenta
Piave
Tagliamento
Isonzo
Soča
Timavo
Reka
Rižana
Dragonja
Mirna
Raša
Arsa
Krka
Zrmanja
Cetina
Neretva
Trebišnjica
Sava
Drina
Una
Vrbas
Bosna
Ukrina
Sana
Kupa
Korana
Mrežnica
Gacka
Lika
Dobra
Una
Sava

zones of pre-Pyrenean ridges—of which the Spanish is the more fully developed—that are now great spurs of the main chain of the Pyrenees.

Under the forces of folding, the more recent and comparatively more plastic layers folded without breaking, but the original rigid base fractured and became dislocated. In the vicinity of the breaks, hot springs appeared and some metal-containing deposits formed. This upheaval affected chiefly the central and eastern regions. During this era, erosion continued incessantly, and, in the most exposed of the raised areas, weathering wore away the softer terrain and uncovered the old Hercynian sedimentary formations, occasionally reaching the deeper granitic bedrock.

Even today the old rocks, slates, schists, limestones transformed into marble (all of which come from old sediments transformed by great pressures and enormous heat), and granites of various kinds make up the spine, or axial zone, of the chain. The geologic phases of this zone, which rises and widens from west to east and ends by sinking, with a steep drop of nearly 9,800 feet, into the depths of the Mediterranean, have determined the evolution of the massif as a whole.

Physiography. The structure of the Pyrenees is characterized by patterns of relief and of underlying structure running in a north–south sequence (like the base rock); these alternate with depressions, some of which are the result of internal deformations, others of erosion of less resistant overlying deposits. In a cross section directly through the central area, where the tectonic activity reached its fullest width and development, it is possible to distinguish, from north to south, two strips of the comparatively recent pre-Pyrenean fold, one Spanish and one French, in juxtaposition with the axial massifs. An outer strip to the north consists of folds constituting the Petites Pyrénées. Cut into channels, they permit the passage of rivers. Nearer the middle of the range rise the Inner Ridges, represented by the mighty cliffs of the Ariège, which contain the primary, or granitic, axial zones. On the Spanish side the series is repeated in the opposite direction, but it is more highly developed and thicker. Thus the Interior Ridges—*e.g.,* Mount Perdido and the massif of Collarada—are sometimes higher than the neighbouring primary axial peaks. They are followed, to the south, by a broad, pre-Pyrenean, middle depression, with a succession of marine and continental deposits of varying hardness that constitute the valleys of such tributaries of the Ebro as the Aragón. This depression continues across the rest of the pre-Pyrenean ridges, among which are new secondary outcrops that form the fringe of Exterior Ridges and the northern rim of the depression of the Ebro; they are not, however, as thick or as important as the Interior Ridges.

North–south sequences of topography

From the structure of their relief and from the climatic conditions (especially on the south) that derive from the geographic situation of the chain, the Pyrenees have been divided into three natural regions: the Eastern (or Mediterranean), Pyrenees, the Central Pyrenees, and the Western Pyrenees. The different vegetation, the linguistic divisions of the people, and—to a point—certain ethnic and cultural distinctions appear to confirm this classification.

Drainage. The hydrographic system consists basically of series of parallel valleys that descend from the high peaks and from the passes. They are bordered by high, dividing ridges in a north–south direction, perpendicular to the axis of the chain. This type of valley produces short, torrential rivers that drop precipitously over short stretches; only seldom do these rivers flow, like the Aragón, through valleys that, as in the Alps, have both gentle slope and greater length. Their flow, extremely variable, especially on the southern side, is heavily influenced by the climate, as well as by the relief. Different maximum low waters occur in summer and winter; the spring, with maximum rain and melting snow, usually sees the greatest flows. In the Western Pyrenees and the northern zone, the rainfall pattern helps produce greater regularity; hence, flow is only slightly lower in summer. On the south a few torrential rivers are fed principally by melting snows, a few largely by rain, but most from a combination of sources.

The river patterns and flow have been important since antiquity in human use of both the land and the rivers—from the floating of timber rafts downstream, which can be done only in the spring, to harnessing waterpower for industry and irrigation on the southern side by means of dams. The torrential flow of many of the rivers is the cause both of the purity of the Pyrenean waters and of their excellence and richness as fishing streams.

The present Pyrenean glaciers, perhaps more frequent on the northern than on the southern slopes, have been reduced to high basins—cirques or hanging valleys—at elevations over 9,800 feet. During and after the great Ice Ages (*i.e.,* within the past 2.5 million years), however, especially in the Central and much of the Eastern Pyrenees, glaciers left widespread erosion and various important sediments. The present-day lower lakes and idyllic meadows with their winding rivulets are among their marks. Glacier tongues were also the main causes of the deep valleys containing the river system.

The fractured areas have many hot springs, both sulfurous and saline. The former are found throughout the axial massif, while the latter occur at the edges. These springs were popular in Roman times and reorganized and modernized toward the end of the 19th century. There are more than 20 famous spas on the French side; those in Spain are as numerous but are less fully exploited.

Climate. Major factors in the climate are the two abutting bodies of water and the extensive continental areas to the north and south. The Atlantic influence penetrates southward across the low peaks of the Western Pyrenees, as far south as Pamplona, Spain, tempering somewhat the differences of climate between the northern and southern slopes. This is not the case in the rest of the chain, especially the Central Pyrenees. The contrast in humidity between the French and Spanish sides is remarkable. To the north the oceanic influence, meeting no obstacles on the French plains of the Aquitaine, penetrates eastward and goes a little beyond the north–south watershed of the French rivers flowing into the Mediterranean. To the east the levanters, winds from the east and southeast, carry damp air from the Mediterranean, some of which falls as precipitation over the southeastern part of the eastern spurs. As a result, these regions are humid, while to the northeast the French depression of the Roussillon acquires Mediterranean characteristics.

Marine and terrestrial influences on climate

South of the Central Pyrenees the valley of the Ebro—which runs in a general northwest–southeast direction and is blocked by the southwest–northeast-trending Catalonian ranges near the eastern coast of Spain—acts as a "little continent." Hence, its climate is one of great thermal contrasts that are exaggerated by the generally high altitude of the Iberian Peninsula, but it is Mediterranean and unlike anything known in other European countries. Thus, the variegated climatic pattern of the Pyrenees ranges from the limpid, sunny atmosphere of the continental zone to the mild mists of the northwest and includes all transition stages in between.

Plant and animal life. Forms of life in the Pyrenees have some remarkable characteristics that cannot be explained merely by the influences of climate and soil. The historical vicissitudes of the chain and its isolation at the southwestern limit of the main European peninsula, far from the centres of dispersion and variation of the various species (including humans), have influenced the structure and character of its population.

In the northwest–southeast direction, the vegetation shows a marked and gradually decreasing oceanic influence; the contrary is the case with the Mediterranean influence from southeast to northwest. The exposure of the mountain surfaces and the conditions of local climate caused by mountain relief create special localized enclaves of all kinds. The most characteristic feature of the oceanic influence is the predominance of broad-leaved deciduous trees in the forests of the lower levels and the medium-height mountains, while the Mediterranean influence, represented by evergreen broad-leaved trees, not only is dominant in hot surroundings but also bears drought conditions better.

The variety of altitudinal vegetation shows itself in levels. From the medium-height mountain upward, the broad-leaved woods at about 5,200 feet are replaced by nee-

Vegetation zones

dled conifers that require less water. The subalpine level, sometimes as low as 6,500 feet but usually above 7,800 feet, gives way to the more sparsely covered pastures of the alpine level. This altitudinal scheme pertains in the vegetation east of the Orhy and Anie peaks. The oceanic influence, however, with its greater rainfall gives the west of the chain a different pattern. Broad-leaved deciduous beeches may be found as high as 5,850 feet, with some mix of the subalpine conifers, and there the high pastures are more resistant to damp and permanent snow. Overall the landscape is more like that of the high mountains of western Europe.

The Mediterranean influence expands through the entire valley of the Ebro, but it acquires marked signs of a more variable continental climate in the Central Pyrenees. There, great quantities of mountain pines, which are more drought-resistant, take the place of deciduous trees in the higher, colder, and drier parts of the medium and higher levels of the southern slopes.

Some groups among the fauna, such as the cave-dwelling animals and frogs and toads, represent a migratory wave that came from ancient Tyrrhenia—associated with Corsica and Sardinia—and displaced certain native European species, relegating them to the Cantabrian Mountains. The Pyrenean fauna is rich today in larger herbivores as well as in the variety and abundance of predators. Some species, such as the wolf, lynx, and brown bear, have disappeared or had their numbers severely reduced in the northern Pyrenees, although the marmot has been successfully reintroduced. The southern Pyrenees, however, represent one of the last important reserves for wild European fauna driven out of sectors more heavily populated by humans. The present distribution and differentiation of large, warm-blooded animals is undoubtedly connected with the climate and the landscape, but the central-European origin of Pyrenean fauna is clear; for example, of the two species of desman (a semiaquatic member of the mole family), one inhabits the Pyrenees and the other southwestern Russia.

Similar comments may be made as to the origin of all cold-blooded animals as well as of the vegetation. Basic differentiations exist among the latter. Pyrenean flora of tropical origin differentiated without any ancient European competition as the new chain replaced the old Hercynian; flora of Arctic origin, brought southward during relatively recent ice ages, are represented by two different branches of orophiles, or plants adapted to mountain life, from central Europe and from Siberia. Other orophiles have long been differentiated, but they are of Mediterranean origin and are dominant in the drier, sunnier parts of the southern slopes. An Atlantic group of flora predominates in the Western Pyrenees.

The people and economy. The Pyrenees are the home of a variety of peoples, including the Andorrans, Catalans, Béarnais, and Basques. Each speaks its own dialect or language, and each desires to maintain and even augment its own autonomy while at the same time acknowledging a general unity among Pyrenean peoples. Of these groups, only the Andorrans have anything approaching a sovereign state, and even then Andorra is an autonomous principality with close ties to both Spain and France. The Basques, perhaps the best-known Pyrenean people, speak a language that is non-Indo-European and have a long tradition of fiercely defending their autonomy.

The Basques

The people of the Pyrenees traditionally have depended on agriculture and livestock raising for their livelihood. The factors that influenced the development of Pyrenean flora also influenced traditional land usage, the kind of crops raised, and the farming system of each district. Typical Mediterranean products such as wines, vegetables, and fruits predominate in the Eastern Pyrenees and at the foot of the chain's southern slope, while in the Western and Central Pyrenees, with their abundant rainfall, potatoes, sweet corn, and forage crops are grown. Livestock breeding, the other essential element of the traditional economy, consists of a seasonal process of moving flocks of sheep and cows up and down the mountains and also using as well as possible the meadows of the valley bottoms and the pastures of the higher altitudes, depending on the snow cover. Frequently in winter, the livestock herds travel far from the Pyrenees, moving to the plains of the Ebro, near the Mediterranean Sea in Languedoc, or to the moors of Aquitaine.

This traditional organization—in which the common exploitation of forest areas for timber also played a large part—has been disappearing slowly. Most farmers are now elderly, and few young people have been willing to settle into the old ways. Gradually, the less fertile plots have been deserted, and the landscape has become dotted by patches of brooms and brackens and plantings of resinous trees. Even local breeds of sheep or cows have been superseded by imported breeds, which perhaps are more profitable but are less adapted to the climate and the relief. Except for such areas as the Basque Country of Spain and the Roussillon region of France, the agriculture of the Pyrenees is in serious decline.

The growing weakness of the Pyrenean agriculture has not been matched by growth in industry. Although the Pyrenees offer considerable hydroelectric potential, the mining of some resources, and an appreciable and diverse supply of wood, most of the mills (steel and paper) and factories (textiles, chemicals, and shoes) established in the 19th and 20th centuries have faced the threat of closing. Except in the two extremities of the chain, most of the

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Cows grazing high in the Central Pyrenees, Huesca province, Spain.

industries are far from any major transportation routes. Scarcely any railroads and no major highways traverse the region, although an express highway is slowly being built between Toulouse, Fr., and Barcelona, Spain. Financed by foreign capital and dependent on the aid of the Spanish and French governments, the remaining factories face an uncertain future.

Perhaps the policies that have been formulated since 1980 by the two Pyrenean countries to develop and protect the mountains may slow down the exile of Pyrenean peoples, who have seen their massif transformed by the tremendous increase in tourism. Although a boon to the local economy, the crowds of people seeking winter sports, summer sojourns, hunting and fishing, and visits to the national parks of the Central Pyrenees have also contributed to the abandonment of traditional ways of life.

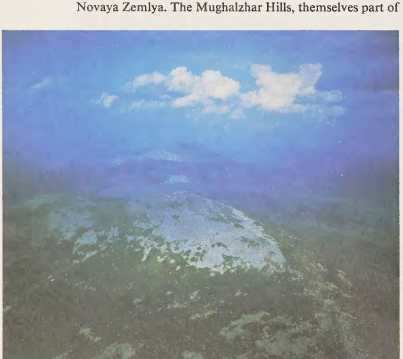
Tourism

Study and exploration. For centuries a general lack of knowledge about the Pyrenees permitted repetition of the errors and misconceptions about the mountains that had been propounded by such authors of antiquity as Diodorus Siculus of Sicily and the Greek geographer-historian Strabo (both 1st century BC). In 1582 the first explorations were made, followed by botanical works from the academies at Montpellier-de-Médillan, Fr., and by other studies, including those of the 18th-century Swiss physicist, geologist, and explorer Horace Bénédict de Saussure. The earliest military map of the region dates from 1719, while early topographical studies were the bases of frontier treaties.

In the 19th century the first topographical and geologic maps were made of the mountains, the latter beginning a series of geologic interpretations and controversies among French and Spanish scientists. German studies added to the interpretive geology, but only in 1933 was the first study made that was based on modern research methods. Since World War II, scientists and scholars from universities, technical institutes, and national councils for research in France and Spain have thoroughly explored the Pyrenees and have produced a wealth of knowledge about the massif. (F.O./Ed.)

URAL MOUNTAINS

The major part of the traditional boundary between Europe and Asia, the Ural Mountains are a rugged spine across the middle of Russia. Extending some 1,550 miles (2,500 kilometres) from the bend of the Ural River in the south to the low, severely eroded Pay-Khoy Ridge, which forms a 250-mile (400-kilometre) fingerlike extension to the northern tip of the Urals proper, they constitute the major portion of the Uralian orogenic belt, which stretches 2,175 miles from the Aral Sea to the northernmost tip of Novaya Zemlya. The Mughalzhar Hills, themselves part of the Uralian orogenic belt, are a broad, arrowhead-shaped southern extension in northwestern Kazakstan that form the divide between the Caspian and Aral basins. The north–south course of the Urals is relatively narrow, varying from about 20 to 90 miles in width, but it cuts across the vast latitudinal landscape regions of the Eurasian landmass, from Arctic waste to semidesert; the Urals also are part of the Ural Economic Region, a highly developed industrial complex closely tied to the mineral-rich Siberian region, and are the home of peoples with roots reaching deep into history.



Nurgush Range, Southern Ural Mountains, Russia.
Tass/Sovfoto

Physical features. *Physiography.* The Urals divide into five sections. The northernmost Polar Urals extend some 240 miles from Mount Konstantinov Kamen in the northeast to the Khulga River in the southeast; most mountains rise to 3,300–3,600 feet (1,000–1,100 metres) above sea level, although the highest peak, Mount Payer, reaches 4,829 feet. The next stretch, the Nether-Polar Urals, extends for more than 140 miles south to the Shchugor River. This section contains the highest peaks of the entire range, including Mount Narodnaya (6,217 feet [1,895 metres]) and Mount Karpinsk (6,161 feet). These first two sections are typically Alpine and are strewn with glaciers and heavily marked by permafrost. Farther south come the Northern Urals, which stretch for more than 340 miles to the Usa River in the south; most mountains top 3,300 feet, and the highest peak, Mount Telpos-Iz, rises to 5,305 feet. Many of the summits are flattened, the remnants of ancient peneplains (eroded surfaces of large area and slight relief) uplifted by geologically recent tectonic movements. In the north, intensive weathering has resulted in vast "seas of stone" on mountain slopes and summits. The lower Central Urals, extending more than 200 miles to the Ufa River, rarely exceed 1,600 feet, though the highest peak, Mount Sredny Baseg, rises to 3,261 feet. The summits are smooth, with isolated residual outcrops. The last portion, the Southern Urals, extends some 340 miles to the westward bend of the Ural River and consists of several parallel ridges rising to 3,900 feet and culminating in Mount Yamantau, 5,380 feet; the section terminates in the wide uplands (less than 2,000 feet) of the Mughalzhar Hills.

The Urals' five sections

The rock composition helps shape the topography: the high ranges and low, broad-topped ridges consist of quartzites, schists, and gabbro, all weather-resistant. Buttes are frequent, and there are north–south troughs of limestone, nearly all containing river valleys. Karst topography is highly developed on the western slopes of the Urals, with many caves, basins, and underground streams. The eastern slopes, on the other hand, have fewer karst formations; instead, rocky outliers rise above the flattened surfaces. Broad foothills, reduced to peneplain, adjoin the Central and Southern Urals on the east.

Geology. The Urals date from the structural upheavals of the Hercynian orogeny (about 250 million years ago). About 280 million years ago there arose a high mountainous region, which was eroded to a peneplain. Alpine folding resulted in new mountains, the most marked upheaval being that of the Nether-Polar Urals. In the watershed region lies the Ural-Tau Anticlinorium (a rock formation of arches and troughs, itself forming an arch), the largest in the Urals, and in the Southern Urals, west of it, is the Bashkir Anticlinorium. Both are composed of layers (sometimes four miles thick) of ancient metamorphic (heat-altered) rocks—gneisses (metamorphic rocks separable into thin plates), quartzites, and schists—that are between 570 and 395 million years old.

The western slope of the Urals is composed of middle Paleozoic sedimentary rocks (sandstones and limestones) that are about 350 million years old. In many places it descends in terraces to the Cis-Ural depression (west of the Urals), to which much of the eroded matter was carried during the late Paleozoic (about 300 million years ago). Found there are widespread karst (a starkly eroded limestone region) and gypsum, with large caverns and subterranean streams. On the eastern slope, volcanic layers alternate with sedimentary strata, all dating from middle Paleozoic times. These rocks compose the Tagil-Magnitogorsk Synclinorium (a group of rock arches and troughs,

Sedimentary rocks of the western slopes

itself forming a trough), the largest in the Urals. In the Central and Southern Urals the eastern slope blends into broad peneplained foothills, where there are frequent outcrops of granite and often fantastically shaped buttes. To the north the peneplain is buried under the loose, easily pulverized deposits of the West Siberian Plain.

Drainage. The rivers flowing down from the Urals drain into either the Arctic Ocean or the Caspian Sea. The Pechora River, which drains the western slope of the Polar, Nether-Polar, and part of the Northern Urals, empties into the Barents Sea. Its largest tributaries are the Ilych, Shchugor, and Usa. Almost all the rivers of the eastern slope belong to the Ob River system, emptying into the Kara Sea. The largest are the Tobol, the Iset, the Tura, the Tavda, the Severnaya (Northern) Sosva, and the Lyapin. The Kama (a tributary of the Volga) and the Ural rivers belong to the drainage basin of the Caspian Sea. The Kama collects water from a large area of the western slope: the Vishera, Chusovaya, and Belaya all empty into it. The Ural River, with its tributary the Sakmara, flows along the Southern Urals.

The location and character of the Urals' rivers and lakes are closely connected with the topography and climate. In their upper reaches many rivers flow slowly through the mountains in wide, longitudinal troughs. Later they change to a latitudinal direction, cut through the ridges in narrow valleys, and descend to the plains, particularly in the Northern and Southern Urals. The main watershed does not correspond with the highest ridges everywhere. The Chusovaya and Ufa rivers of the Central and Southern Urals, which later join the Volga drainage basin, have their sources on the eastern slope.

The rivers on the western slope carry more water than those of the east, particularly in the Northern and Nether-Polar Urals; the slowest rate of flow is on the eastern slope of the Southern Urals, reflecting intense evaporation as well as low precipitation. In winter the rivers freeze for five months in the south and for seven months in the north.

There are many lakes, especially on the eastern slope of the Southern and Central Urals. The largest are Uvildy, Itkul, Turgoyak, and Tavatuy. On the western slope are many small karst lakes. In the Polar Urals, lakes occur in glacial valleys, the deepest of them being Lake Bolshoye Shchuchye, at 446 feet deep. Medicinal muds are common in a number of the lakes, such as Moltayevo, and spas and sanatoriums have been established.

Climate. The climate is of the continental type, marked by temperature extremes that become increasingly evident both from north to south and from west to east. The Pay-Khoy Range and the Polar Urals enjoy the moderating influence of the Arctic and the North Atlantic oceans, particularly in winter. In the Mughalzhar Hills and the Southern Urals there are summer winds of hot, dry air from Central Asia. Winds are for the most part westerly and bring precipitation from the Atlantic Ocean. In spite of their low elevation, the mountains exert a considerable influence on the moisture distribution, and the western slope receives more moisture than the eastern. Precipitation is particularly heavy on the western slope of the Nether-Polar and Northern Urals, as high as 40 inches (1,000 millimetres). Northward and southward precipitation diminishes to about 18 inches. On the eastern slope there is less moisture (about 12 inches) and snow. Annual snow depth on the western slope averages 35 inches and on the eastern, 18 inches. Maximum precipitation occurs in the summer, for the cold, dry air of the Siberian anticyclone is powerful in winter. The eastern slope is particularly chilled, and winter lasts longer than summer throughout the Urals. In January the average temperature in the north is −6° F (−21° C), and in the south the average is 5° F (−15° C). Average temperatures in July vary more, between 50° F (10° C) in the north and 72° F (22° C) in the south.

Precipitation

Plant life. The Urals pass through several vegetation zones, with the northern tundra giving way to vast mixed forests, while still farther south is the steppe, culminating in semidesert around the Mughalzhar Hills. Feather grass and meadows predominate on the chernozems (black earth) and dark chestnut soils (a characteristic steppe soil).



The Ural Mountains.

Other characteristic growths are clover, fescue (a pasture grass), and timothy (a grass grown for hay). South of the Ural River the steppes give way to wormwood and semidesert growths on light chestnut soils (again typical steppe soil), which are highly saline in places.

The forest landscapes of the Urals are varied. The more humid western foothills of the Southern Urals are covered mostly by mixed forests growing on a gray mountain-forest type of soil. There, such broad-leaved species as oak, small-leaf linden, and elm are mixed with Siberian fir and Siberian spruce. The broad-leaved forests extend to 2,100 feet, above which conifers appear. On the eastern slope there are no broad-leaved trees except the linden, and magnificent pine forests with some larches are widespread.

Farther to the north, in the Central Urals, boreal forests (taiga) of spruce, fir, pine, and larch grow on the

mountain, podzolic soils. In the more northerly regions, dark conifers are common, and, in the Northern Urals, the Siberian cedar is widespread. There forests climb to 2,800 feet or so, above which is a narrow belt of larch and birch, trailing off to forest yields to mountain tundra at and Polar Urals the forest yields to mountain tundra at elevations as low as 1,300 feet. Whereas moss tundra is generally found on the more humid western slope, lichen tundra is common on the eastern. There are numerous sphagnum moss marshes on both slopes. Only brushwood and moss–lichen tundra grows on the Pay-Khoy Ridge.

Animal life. There are no specifically mountain animals in the Urals, primarily because of the low elevations and easy accessibility, and fauna differs little from that of the adjacent areas of eastern Europe and western Siberia. The most valuable animal of the tundra is the Arctic fox. Ob lemmings, snowy owls, tundra partridge, and reindeer are other inhabitants, though the latter are few. Many wild ducks, geese, and swans breed there in summer. But the richest and most varied fauna in the Urals, including the brown bear, lynx, wolverine, and elk, are found in the forested zones. Some have valuable furs: the sable (in the north), ermine, fox, marten (in the south), Siberian weasel, and squirrel. In the taiga there are such birds as the wood grouse, black grouse, capercaillie (another member of the grouse family), cuckoo, and hazel hen (a woodland grouse). In the mixed, broad-leaved forests of the Southern Urals' western slopes live roe deer, badgers, and polecats, as well as many birds typical of the European part of Russia, such as the nightingale and oriole. The commonest animals of the steppe and semidesert regions are rodents, including susliks (a type of ground squirrel), jerboas (a social, nocturnal, jumping rodent), and other agricultural pests. The rivers and lakes of the Northern Urals abound in fish, the most valuable being the nelma (a species related to the whitefish), common salmon, grayling, and sea trout. Farther south, in the densely populated and industrial regions, animal life is less abundant.

Similarity of fauna in adjacent regions

The vigorous economic development and growth in population that have occurred in the Urals in the 20th century have altered considerably the chain's landscape and the abundance of wildlife. Conservation measures during the Soviet period included establishing national nature preserves such as Pechoro-Ilych in the Northern Urals, Basegi and Visim in the Central Urals, and Ilmen and Bashkir in the Southern Urals.

The people. Human habitation of the Urals dates to the distant past. The Nenets are a Samoyed people of the Pay-Khoy region, and their language belongs to the Samoyedic group of languages, which is widespread throughout northern Siberia. Farther south live the Komi, Mansi, and Khanty, who speak a tongue belonging to the Ugric group of the Finno-Ugric languages. The most numerous indigenous group, the Bashkir, long settled in the Southern Urals, speak a tongue related to the Turkic group. Some Kazak live in the Mughalzhar Hills of Kazakstan. Most of these formerly nomadic peoples are now settled. The Nenets, Komi, Mansi, and Khanty are virtually the only inhabitants in the highest parts of the Urals, especially in the north, where they have preserved their traditional ways of life—raising reindeer, hunting, and fishing. The Bashkir are excellent horse breeders. The indigenous peoples, however, now constitute only about one-fifth of the total population of the Urals; the great majority are Russians. The Russian population is concentrated primarily in the Central and Southern Urals, and most people live in cities—notably Yekaterinburg (formerly Sverdlovsk), Chelyabinsk, Perm, and Ufa—and work in industries. Agricultural populations predominate in the steppe region of the Southern Urals, where conditions are favourable for wheat, potatoes, and other crops.

The economy. The Urals are extremely rich in mineral resources, with variations on the eastern and western slopes according to geologic structure. Ore deposits, for example, notably magnetite, predominate on the eastern slope, where contact (the surface where two different rock types join) deposits are found, as at Vysokogorsk and Mount Blagodat, as well as magmatic deposits (formed from liquid rock), as at Kachkanar. Some of the ore deposits, such as the magnetite ores at Magnitogorsk, are exhausted or nearly depleted. Sedimentary deposits are of less importance. Some ores contain alloying metals—vanadium, a gray-white resistant element, and titanium—as impurities. The largest copper ore deposits are at Gay and Sibay, and nickel ores are found at Ufaley. There are also large deposits of bauxite, chromite, gold, and platinum.

Mineral resources

Among the nonmetallic mineral resources of the eastern slope are asbestos, talc, fireclay, and abrasives. Gems and semiprecious stones have long been known: they include amethyst, topaz, and emerald. Among the western deposits are beds of potassium salts on the upper Kama River and petroleum and natural gas deposits in the Ishimbay and Krasnokamsk areas. Bituminous coal and lignite are mined on both slopes. The largest deposit is the Pechora bituminous coalfield in the north.

The vast forests of the Urals are also of great economic importance: not only do they yield valuable wood, but they also regulate the flow of the rivers and shelter many of the valuable fur animals. Agriculture is significant mainly in the eastern steppe region of the Southern Urals. Much of the land there has been plowed for cultivation, and in large areas wheat, buckwheat, millet, potatoes, and vegetables are grown.

Because of its wealth of mineral resources, the leading industries in the Urals are mining, metallurgy, machine building, and chemicals. Of national importance are the metallurgical plants at Magnitogorsk, Chelyabinsk, and Nizhny Tagil; chemical plants at Perm, Ufa, and Orenburg; and large-scale engineering at Yekaterinburg.

Study and exploration. The existence of the Riphean and Hyperborean mountains at the eastern fringe of Europe in antiquity was regarded as being more mythical than real. Not until the 10th century AD does the first mention of the Urals occur, in Arabic sources. At the end of the 11th century the Russians discovered the northernmost part of the Urals, but they did not complete the discovery of the entire range until the beginning of the 17th century, when the mineral wealth of the Urals was discovered. The first geographic survey of the chain was made in the early 18th century by the Russian historian and geographer Vasily N. Tatishchev, who undertook the survey for Peter I the Great. Systematic extraction of iron and copper ore also began at that time, and the Urals rapidly became one of the largest industrial regions of Russia.

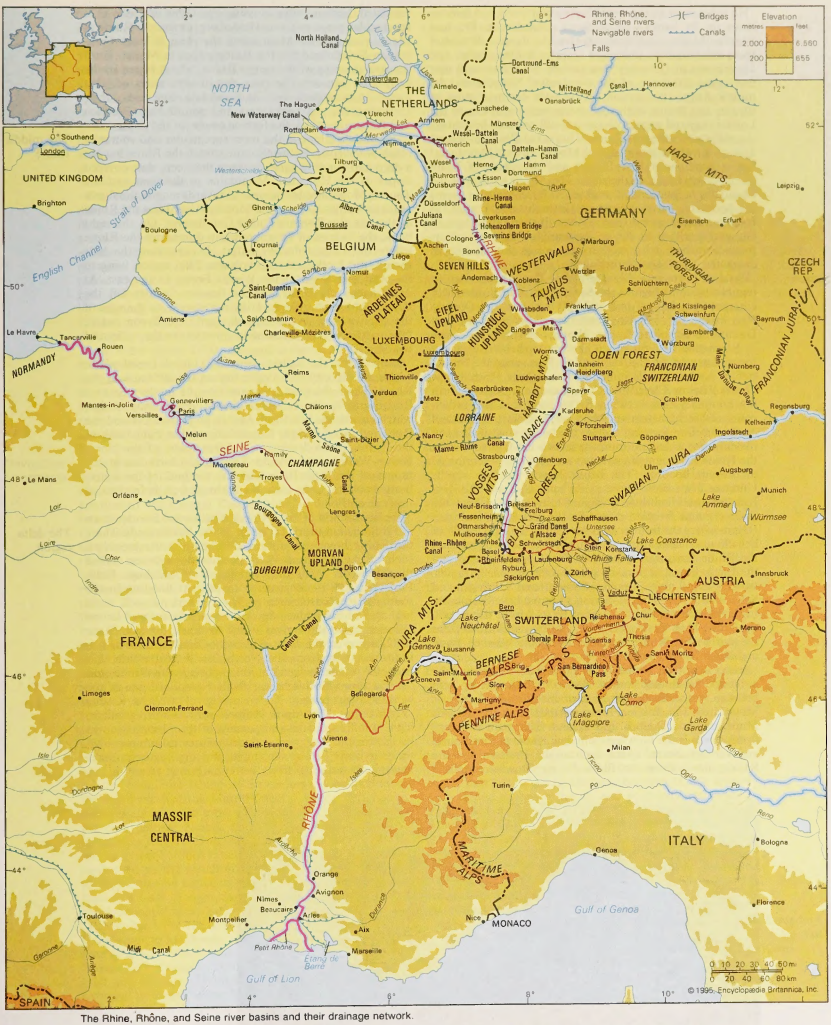
The first serious scientific study of the Urals was made in 1770–71. Scholars studying the Urals during the 19th century included several Russian scientists, such as the geologist A.D. Karpinsky, the botanist P.N. Krylov, and the zoologist L.P. Sabaneev, and also such prominent foreign scholars as the German naturalist Alexander von Humboldt and the English geologist Sir Roderick Murchison, who compiled the first geologic map of the Urals in 1841. Much work was done in the Soviet period on geologic structure and associated mineral resources. (Y.V.Y.)

Western European drainage systems

RHINE RIVER

Culturally and historically one of the great rivers of Europe and among the most important arteries of industrial transport in the world, the Rhine River flows 865 miles (1,390 kilometres) from east-central Switzerland north and west to the North Sea, into which it drains through The Netherlands. The German spelling is Rhein; Dutch, Rijn; French, Rhin—all derived from the Latin, Rhenus. An international waterway since the Treaty of Vienna in 1815, it is navigable overall for some 540 miles, as far as Rheinfelden on the Swiss-German border. Its catchment area, including the delta area, exceeds 85,000 square miles (220,000 square kilometres).

The Rhine has been a classic example of the alternating roles of great rivers as arteries of political and cultural unification and as political and cultural boundary lines. The river also has been enshrined in the literature of its lands, especially of Germany, as in the famous epic *Nibelungenlied.* Since the time when the Rhine valley became incorporated into the Roman Empire, the river has been one of Europe's leading transport routes. Until the



The Rhine, Rhône, and Seine river basins and their drainage network.

19th century the goods transported were of high value but relatively small in volume, but since the second half of the 19th century the volume of goods conveyed on the river has increased greatly. The fact that cheap water transport on the Rhine helped to keep prices of raw materials down was the main reason the river became a major axis of industrial production: one-fifth of the world's chemical industries are now manufacturing along the Rhine. The river was long a source of political dissension in Europe, but this has given way to international concern for ecological safeguards as pollution levels have risen; some 6,000 toxic substances have been identified in Rhine waters.

No other river in the world has so many old and famous cities on its banks—Basel, Switz.; Strasbourg, Fr.; and Worms, Mainz, and Cologne, Ger., to name a few—but there are also such industrial cities as Ludwigshafen and Leverkusen in Germany that pollute the waters and mar the scenic attraction of the riverbanks. Nonetheless, the middle Rhine (the section between the German cities of Bingen and Bonn), with such steep rock precipices as the Lorelei crag and numerous castles, still presents breathtaking vistas and attracts tourists. This is the Rhine of legend and myth, where the medieval Mouse Tower (Mausturm) lies at water level near Bingen and the castle of Kaub stands on an island in the river. The Alpine section of the Rhine lies in Switzerland, and below Basel the river forms the boundary between western Germany and France, as far downstream as the Lauter River. It then flows through German territory as far as Emmerich, below which its many-branched delta section epitomizes the landscapes characteristic of The Netherlands.

Source

Physical features. *Physiography.* The Rhine rises in two headstreams high in the Swiss Alps. The Vorderrhein emerges from Lake Toma at 7,690 feet, near the Oberalp Pass in the Central Alps, and then flows eastward past Disentis to be joined by the Hinterrhein from the south at Reichenau above Chur. (The Hinterrhein rises about five miles west of San Bernardino Pass, near the Swiss–Italian border, and is joined by the Albula River below Thusis.) Below Chur, the Rhine leaves the Alps to form the boundary first between Switzerland and the principality of Liechtenstein and then between Switzerland and Austria, before forming a delta as the current slackens at the entrance to Lake Constance. In this flat-floored section the Rhine has been straightened and the banks reinforced to prevent flooding. The Rhine leaves the lake via its Untersee arm. From there to its bend at Basel, the river is called the Hochrhein ("High Rhine") and defines the Swiss-German frontier, except for the area below Stein am Rhein, where the frontier deviates so that the Rhine Falls at Schaffhausen are entirely within Switzerland. Downstream the Rhine flows swiftly between the Alpine foreland and the Black Forest region, its course interrupted by rapids, where—as at Laufenburg (Switzerland) and Säckingen and Schwörstadt (Germany)—barrages (dams) have been built. In this stretch the Rhine is joined by its Alpine tributaries, the Thur, Töss, Glatt, and Aare, and by the Wutach from the north. The Rhine has been navigable between Basel and Rheinfelden since 1934.

Below Basel the Rhine turns northward to flow across a broad, flat-floored valley, some 20 miles wide, held between, respectively, the ancient massifs of the Vosges Mountains and Black Forest uplands and the Haardt Mountains and Oden Forest upland. The main tributary from Alsace is the Ill, which joins the Rhine at Strasbourg, and various shorter rivers, such as the Dreisam and the Kinzig, drain from the Black Forest. Downstream, the regulated Neckar, after crossing the Oden uplands in a spectacular gorge as far as Heidelberg, enters the Rhine at Mannheim; and the Main leaves the plain of lower Franconian Switzerland for the Rhine opposite Mainz. Until the straightening of the upper Rhine, which began in the early 19th century, the river described a series of great loops, or meanders, over its floodplain, and today their remnants, the old backwaters and cutoffs near Breisach and Karlsruhe, mark the former course of the river.

The middle Rhine

The middle Rhine is the most spectacular and romantic reach of the river. In this 90-mile stretch the Rhine has cut a deep and winding gorge between the steep, slate-covered slopes of the Hunsrück Mountains to the west and the Taunus Mountains to the east. Vineyards mantle the slopes as far as Koblenz, where the Moselle River joins the Rhine at the site the Romans called Confluentes. On the right bank, the fortress of Ehrenbreitstein dominates the Rhine where the Lahn tributary enters. Downstream the hills recede, the foothills of the volcanic Eifel region lying to the west and those of the Wester Forest to the east. At Andernach, where the ancient Roman frontier left the Rhine, the basaltic Seven Hills rise steeply to the east of the river, where, as the English poet Lord Byron put it, "the castle crag of Dachenfels frowns o'er the wide and winding Rhine."

Below Bonn the valley opens out into a broad plain, where the old city of Cologne lies on the left bank of the Rhine. There the river is spanned by the modern Severin Bridge and by the rebuilt Hohenzollern railway bridge, which carries the line from Aachen to Düsseldorf and the Ruhr industrial region. Düsseldorf, on the right bank of the Rhine, is the dominant business centre of the North Rhine–Westphalia coalfield. Duisburg, which lies at the mouth of the Ruhr River, handles the bulk of the waterborne coal and coke from the Ruhr as well as imports of iron ore and oil.

The delta region

The last section of the Rhine lies below the frontier town of Emmerich in the delta region of The Netherlands. There the Rhine breaks up into a number of wide branches, such as the Lek and Waal, farther downstream called the Merwede. With the completion of the huge Delta Project in 1986—constructed to prevent flooding in the southwestern coastal area of The Netherlands—all main branches of the Rhine were closed off; sluices and lateral channels now allow river water to reach the sea. Since 1872, however, the New Waterway Canal, constructed to improve access from the North Sea to Rotterdam, has been the main navigation link between the Rhine and the sea; along this canal was built Europoort, one of the world's largest ports. (A.F.A.M./K.A.Si.)

Hydrology. The Alpine Rhine—with its steep gradient, high runoff coefficient (80 percent of the precipitation in its catchment area), pronounced winter minimum, high water in spring from snowmelt, and high early summer maximum resulting from heavy summer rains—has a

J. Allan Cash



Meander in the Rhine River valley at Boppard, Ger., just south of the confluence with the Moselle River.

characteristic Alpine regime. Although variations in flow are evened out by Lake Constance, which is fed by upland streams as well as by the Rhine (and which also acts as a filter), they are increased again by the confluence with the Aare, which on an average carries more water than the Rhine. Below Basel, however, the tributaries from the uplands, with their spring maximums at higher and winter maximums at lower elevations, increasingly moderate the unbalance. Thus, at Cologne the average deviations from mean flow are slight, and the regime is favourable to navigation. Winters in the navigable regions of the river, moreover, are generally mild, and the Rhine freezes only in exceptional winters.

The economy. As a commercial artery, the Rhine is unrivaled among the world's rivers, historically as well as in the amount of traffic carried. The Romans maintained a Rhine fleet, and the importance of the river increased enormously with the rise of medieval trade, which relied on water transport wherever possible because of the poor roads. The rock barrier of the gorge at Bingen divided navigation into two sections: predominantly upstream traffic by seagoing vessels to Cologne and predominantly downstream movement of commodities—brought first across the Alpine passes—from Basel to Mainz and Frankfurt am Main. After about 1500, navigation declined because of reorientation of trade toward the Atlantic and political disintegration of the Rhineland. The rise of modern navigation began in the 19th century, and its present magnitude is attributable largely to four factors: removal of political restrictions on navigation, physical improvements to the navigation channel, canalization of the Rhine's hinterland, and increasing industrialization of the riparian countries.

Navigation agreements

The principle of free navigation on the Rhine was agreed upon by the Congress of Vienna in 1815 and was put into effect by the Mainz Convention of 1831, which also established the Central Commission of the Rhine. This first treaty was simplified and revised in the Mannheim Convention of 1868, which, with the extension in 1918 of all privileges to ships of all countries and not merely the riverine states, remains (broadly speaking) in force.

Navigational improvements. Historically, two sections presented serious handicaps to navigation: the rock barrier at Bingen and the southern upper Rhine. At Bingen two navigation channels were blasted out in 1830–32; canalization of the upper Rhine by confining it within an artificial bed and straightening its course was undertaken in 1817–74. In neither case were the resulting improvements entirely satisfactory, but the channels at Bingen were doubled in width and deepened, thus eliminating the need for a pilot. Navigation on the upper Rhine, despite the further improvements made after 1907, suffers from seasonal variations of flow and the swift current.

To improve navigation and to procure hydroelectric power, France (by the Treaty of Versailles) obtained the right to divert Rhine water below Basel into a canal that was to rejoin the Rhine at Strasbourg. Construction of the first section of this Grand Canal d'Alsace, designed to take vessels of 1,500 tons, was completed with the building of a dam at Kembs in 1932 and greatly improved navigation. Construction was resumed after World War II, but in a treaty (1956) France, in return for West German agreement to the canalization of the Moselle, consented to terminate the canal at Neu Breisach. The remaining four of a total of eight dams utilize Rhine water by the construction of canal loops only.

Below Basel the Huningue branch of the Rhine–Rhône Canal leads to Mulhouse, where it meets the main arm of that waterway, which joins the Rhine at Strasbourg. The Rhine–Rhône Canal (1810–33) is navigable by 300-ton craft and carries only moderate traffic. More important, although no larger, is the Rhine–Marne Canal (1838–53), which also joins the Rhine at Strasbourg.

The Neckar is canalized through Stuttgart as far as Plochingen and the Main as far as Bamberg. There, the completed northern portion of the Main–Danube Canal leads south to Nürnberg, which has become an important port. A treaty signed in 1956 between West Germany, France, and Luxembourg provided for canalization of the Moselle from Koblenz to Thionville (170 miles), which was completed in 1964. The Lahn also is canalized for small (200-ton) craft for 42 miles.

In the Ruhr region the Ruhr itself (except for the last seven miles) and the Lippe are not used as waterways. Their place is taken by the Rhine–Herne Canal, completed in 1916 between Duisburg and Herne and linking the Rhine through the Dortmund–Ems Canal with the German North Sea coast and through the Mittelland Canal with the waterways of central and eastern Germany and eastern Europe; and by the less important Wesel–Datteln–Hamm Canal (1930), which runs parallel to the lower course of the Lippe. The Rhine–Herne Canal's capacity for craft of 1,350 tons became the standard both for the minimum capacity of canals built since World War II and for barges. Nearer the Rhine's mouth, the Merwede Canal (enlarged 1952) south of Amsterdam provides another route to the sea for ships displacing as much as 4,300 tons.

Growth of the Rhine as a waterway

Traffic. Three factors were important in the rise of traffic on the Rhine. First, the political impediments to free navigation—particularly the approximately 200 toll stations along the course of the river—were removed by the Congress of Vienna of 1815. Second, the means of transport were improved by the introduction of steam-powered, and later diesel-powered, tugs; prior to the mid-19th century, barges moving upstream were towed either by teams of horses or gangs of men. Third, the waterway itself was improved, the stages of which are discussed above.

The first steamship voyage on the Rhine was made from London to Koblenz in 1817, but this was a solitary event. The harbour installations of Mannheim were opened in 1840, and for almost a century this was the effective head of navigation. Although Basel had been reached by a steamship by 1832, its development as a Rhine port started a century later. Despite the improvement of the navigation and means of transport, there was at first little growth in the volume of transport. Increase came with the rise of modern industry in the 19th century, which necessitated the bulk movement of coal, ore, building materials, raw material for the chemical industry, and (since about 1950) oil. Although coal and ore transport declined, there was an overall increase in the volume of transport until the mid-1960s; since then, however, freight tonnage has decreased to about a third of its former level.

The mode of transport from 1840 onward was by tugs towing a number of barges. Development after 1945 involved initially the introduction of self-propelled barges and subsequently the introduction of push tugs, whereby one tug can propel four-barge units and thus save labour costs. An increase in the traffic volume was also effected by the introduction of radar navigation in the 1950s, which made round-the-clock operation possible. There is also regular passenger service on the Rhine during summer, especially the middle Rhine section and from Rotterdam to Basel, but this is almost exclusively for tourists.

History. The effects of rivers on the regions through which they flow tend to alternate between trends toward unifying the regions culturally and politically and making a political boundary of the river. Of this phenomenon the Rhine is a classic example. During prehistoric times the same culture groups existed on both banks; similarly, in early historic times Germanic tribes settled on either side of its lower and Celts alongside its upper course. Although bridged and crossed by Julius Caesar in 55 and 53 BC, the Rhine became for the first time, along its course from Lake Constance to its mouth at Lugdunum Batavorum (Leiden, Neth.), a political boundary—that of Roman Gaul. This division did not endure for long, because under the emperor Augustus the provinces of Germania Superior and Germania Inferior were established on the other side of the Rhine, and south of Bonna (Bonn) the boundary of the Roman Empire was marked by the limes (Roman fortified frontier) well east of the river. Nevertheless, because the Rhine had been the boundary of Gaul for a time, it resulted in later claims by France, esteeming itself the successor to Gaul, to the Rhine as its natural boundary. When the Western Roman Empire disintegrated, the Rhine was crossed along its entire length by Germanic tribes (AD 406), and the river formed the central backbone first of the kingdom of the Franks and then of the Car-

Boundary of Roman Gaul

olingian empire. When in 843 that empire was divided, stretches of the Rhine formed the eastern boundary of the central part, Lotharingia, until 870 when the Rhine again became the central axis of a political unit, the Holy Roman Empire. Subsequent events shifted the axis of this empire eastward and caused political disintegration along the Rhine. The Thirty Years' War (1618–48) ended with the final separation of the Rhine headwaters and delta area from Germany and a gradual advance of France toward the Rhine, which it reached under Louis XIV through his acquisition of Alsace.

The French Revolutionary Wars included further French advances, and the Treaty of Lunéville (1801) made the Rhine, along most of its course, France's eastern boundary. But France advanced beyond the Rhine and included northwestern Germany within its borders, and the Confederation of the Rhine, created by Napoleon, extended French control as far as the Elbe and Neisse rivers. The resultant upsurge of German nationalism was expressed by E.M. Arndt, who in 1813 wrote, "The Rhine is Germany's river, not its boundary." The Congress of Vienna, nevertheless, left France in possession of Alsace and thus with a Rhine frontier. Ambitions of Napoleon III to acquire further Rhenish territory strongly aroused German feelings. In 1840 Max Schneckenburger wrote his patriotic poem "Die Wacht am Rhein" ("The Watch on the Rhine"), which was set to music by Karl Wilhelm in 1854 and became the rousing tune of the Prussian armies in the Franco-German War of 1870–71. One result of this war was that France lost Alsace and thus its Rhine frontier, which it regained after World War I.

The fortified defensive system of the Maginot Line (built in 1927–36) adjoined the French bank of the upper Rhine from the Swiss frontier to near Lauterbourg. The opposing *Westwall,* or Siegfried Line (1936–39), adjoined the German bank from the Swiss frontier to near Karlsruhe.

Events after World War II suggested that the struggle for possession of the Rhine had been superseded by a trend toward economic and even political union of the riparian states. In addition, the increased pollution of the Rhine has resulted in growing international cooperation to combat the threat. (K.A.Si.)

RHÔNE RIVER

The Rhône, a historic river of Switzerland and France and one of the most significant waterways of Europe—it is the only major river flowing directly to the Mediterranean Sea—is thoroughly Alpine in character. In this respect it differs markedly from its northern neighbour, the Rhine, which leaves all of its Alpine characteristics behind when it leaves Switzerland. The scenic and often wild course of the Rhône, the characteristics of the water flowing in it, and the way it has been used by humans have all been shaped by the influences of the mountains, right down to the river mouth, where sediments marking the Rhône's birth in an Alpine glacier are carried into the warmer waters of the Mediterranean.

The Rhône is 505 miles (813 kilometres) long and has a drainage basin of some 37,750 square miles (97,775 square kilometres). The course of the river can be divided into three sectors lying, respectively, in the Alps, between the Alps and the Jura Mountains and through the latter, and finally in the topographical furrow of Alpine origin running from the city of Lyon to the sea.

Physical features. *Physiography.* The Rhône originates in the Swiss Alps, upstream from Lake Geneva. It comes into being at an altitude of about 6,000 feet (1,830 metres), emerging from the Rhône Glacier, which descends the south flank of the Dammastock, a nearly 12,000-foot peak. The river then traverses the Gletsch Basin, from which it escapes through a gorge, and flows along the floor of the Goms Valley at an altitude between 4,000 and 4,600 feet. It next enters another gorge before reaching the plain of the Valais, which extends between the towns of Brig and Martigny, and descends in altitude 2,300 to 1,600 feet. In crossing this high and rugged mountain area, the river makes successive use of two structural troughs. The first runs between the ancient crystalline rock massifs of the Aare and of the Gotthard; farther downstream the second runs between the arched rock mass of the Bernese Oberland and, on the south, the massive rock face of the Pennine Alps. From Brig onward, the landscape changes. During the last Ice Age a large glacier, fed by several small ones, plowed down the valley floor of the Valais, and, except for some harder rock obstacles found near the town of Sion, succeeded in widening and deepening the narrow valley floor. As it did so, it held back both the upper Rhône and those of its tributaries that come down from the Pennine Alps. When the ice sheets retreated, both the tributaries—the Vispa, Navigenze, Borgne, and Drance—and the Rhône cut new, deep gorges to connect their lower courses to the new valley floor. These gorges have created considerable difficulty for modern transportation, necessitating a series of hairpin-bend road links.

The Alpine sector

After Martigny, where the valley floor is wider, the youthful Rhône thrusts northward at a right angle, cutting across the Alps through a transverse valley. At first, near the town of Saint-Maurice, this is no more than a small gorge, but it soon becomes wider and flatter. There, too, the river route has been assisted by structural factors, specifically by a dip in the crystalline rock massifs running from Mont Blanc to the Aare and by the discontinuity between the limestone masses of the Dents du Midi and of the Dent de Morcles. Across the mountain barrier the muddy waters of the Rhône enter another wide plain surrounded by high mountains and then plunge into the clearer, stiller waters of Lake Geneva, forming an enlarging delta.

The second sector of the Rhône's course commences with Lake Geneva, large (224 square miles) and deep (1,000 feet) and lying between Switzerland and France in a basin hollowed out of the less resistant terrain by the former Rhône Glacier. Upon leaving Lake Geneva, which has turned the course of the river to the southwest and decanted the sediment from its waters, the Rhône very quickly regains in full the milky colour so characteristic of Alpine rivers. Just below the city of Geneva, it receives its powerful tributary the Arve, which rushes down from the glaciers of Mont Blanc.

The middle course

From its juncture with the Arve to the French city of Lyon, the Rhône has to cross a difficult obstacle, the undulating series of ridges forming the Jura Mountains. It does this by cutting through deep longitudinal valleys called *vaux* and transverse valleys called *cluses,* which were formed when the Jura Mountains were uplifted during the Alpine orogeny. As a result, the river follows a complicated zigzag course. At the town of Bellegarde the river is joined from the north by the Valserine and, swinging south, plunges into a deep gorge now submerged in the 14-mile-long Génissiat Reservoir. In the wider sections of its course in this region, the Rhône runs through glacier-excavated basins that its own deposits have barely filled, causing intermittent marshy areas. It is also joined by the Ain, from the north, and, on the left bank, by the Fier and Guiers. The river next widens, and the terrain becomes less hilly and, at Le Parc (some 95 miles above Lyon), becomes officially navigable, although the average depth is no more than three feet.

The lower sector

At Lyon the Rhône enters its third sector as it heads south toward the Mediterranean, which is characterized by the great north–south Alpine furrow that is also drained by its principal tributary, the Saône. The latter lies in the basins that the Ice Age glaciers hollowed out between the Jura Mountains to the east and, farther west, the eastern edge of the Paris Basin and the uplands of the Massif Central. It forms an important commercial link to the industrialized regions of northern France. From the city of Lyon onward, the river occupies the trough lying between the Massif Central and the Alps, a channel up which the sea of the Tertiary period (66.4 to 1.6 million years ago) ascended covering the present Rhône valley. A body of water, Lake Bresse, spread over the Saône basin. Into this lake drained a river—the present Rhine—which then flowed south through the valley and into the Saône basin; later tectonic movements caused the Rhine to reverse its flow, and the Doubs, a tributary of the Saône, now partly follows the former Rhine drainage pattern. In the late Tertiary the gulf of the sea was uplifted to expose the lower Rhône valley, and Lake Bresse drained out to the

south through the Saône River. Though the Rhône–Saône corridor is underlain by sediments laid down during the Tertiary period, much of its present surface is formed by debris deposited by valley glaciers that extended from the Alps during the Pleistocene epoch (1.6 million to 10,000 years ago). These sediments were instrumental in cutting deep channels through the edge of the crystalline Massif Central, as evidenced at Vienne and Tain. The valley consequently takes the form of a series of gorges and basins, the latter often having a series of terraces corresponding to variations in the levels of ice and of river. Although the tributaries—notably the Ardèche—rushing down into the Rhône from the Massif Central are formidable when in flood, the great Alpine rivers, the Isère, and the Durance, joining the left bank, are most important in their effect on riverbed deposits and on the volume of water. Below Mondragon the Rhône valley becomes wider, and what was once a marshy landscape open to flooding has been regulated by a series of dams and canals.

The river's delta begins near Arles and extends about 25 miles to the sea. Twin channels of the river, the Grand and Petit Rhône, enclose the Camargue region. This region, formed by alluvium, is continuously extending into the Mediterranean. The finer materials are carried by onshore currents to form the barrier beaches of the coast and the sandbars closing off the Étang de Berre. One part of the delta has been set aside for a nature reserve, thereby protecting the feeding and nesting grounds of flamingos, egrets, ibis, and other rare species. Since 1962 the left bank of Fos has been transformed into a vast industrial complex consisting of port facilities, refineries, oil-storage tanks, and steel mills.

Hydrology. The flow regime of the Rhône owes its remarkable mean volume to the influence of the Alps. At Lyon the flow amounts to 22,600 cubic feet (640 cubic metres) per second; there, the Saône alone contributes 14,100 cubic feet per second. The Isère adds another 12,400 cubic feet per second. The melting of the Alpine snows gives the highest mean flows in May, while the Saône attains its maximum in January. The flood volumes of spring and autumn are formidable, reaching 460,000 cubic feet per second for the Rhône at Beaucaire, just above the delta. Thus, the Rhône has an abundant flow but maintains a strong gradient almost to its mouth. At Lyon, for example, its altitude is 560 feet at 205 miles from the sea. As the size of the delta region testifies, the river transports enormous amounts of alluvial deposits and is also powerful enough to cut through a variety of rock masses. As a result, the Rhône of today is well adapted to the production of electricity and, though difficult to navigate in the past, is now an important waterway from the Mediterranean to Lyon.

Flood volumes

The economy. The Rhône basin constitutes one of the great economic regions of Switzerland and of France, draining rich plains as well as an important part of the Alps. The utilization of the region by humans, however, has required a long historical struggle, which entered a decisive phase only in the second half of the 20th century. The economy of the Rhône region consists of five major elements: agriculture, industry, energy, tourism, and transportation.

Agriculture in the Rhône valley largely covers the low areas, plains, and islands. In the canton of Valais, the Rhône has been diked and narrowed, and the surrounding plain has been drained. Comparable works have been carried out in France, notably on the Isère, at Combe de Savoie and Grésivaudan, and on the upper Durance. River waters are used extensively for irrigation. Forage crops and livestock raising coexist with vineyards, fruit orchards, and vegetable farming; the Camargue region is noted for its rice fields.

Industries, both large and small, have been established throughout the region. Notable concentrations include the aluminum and chemical plants in Valais, the oil refineries at Lyon, and the refineries and steel mills at Fos. The production of hydroelectricity is evident throughout the length of the Rhône and particularly so in its lower reaches, where a series of dam projects have harnessed more than half of the entire potential hydroelectric power of the river. In France several nuclear generating stations utilize river waters for cooling purposes.

The course of the Rhône has long attracted tourists, and tourism has played an increasingly key role in the regional economy since the mid-20th century. The great variety of recreational activities offered—from skiing and climbing in the Alps, to visiting the historic cities of Provence, to horseback riding in the Camargue—have been key to the river's popularity.

Transportation

Navigation has always been carried on, particularly between Lyon and the sea, and the Rhône traditionally has been the transportation funnel between northern and southern France; the Rhône valley in Valais served a similar function in Switzerland, particularly with the construction of a number of rail and road tunnels under some of the mountain barriers. The most extensive improvements to the river itself have taken place between Lyon and the Mediterranean: shoals have been submerged under the reservoirs created by dams or bypassed by canals, and the original gradient has been replaced by a succession of level reaches and locks.

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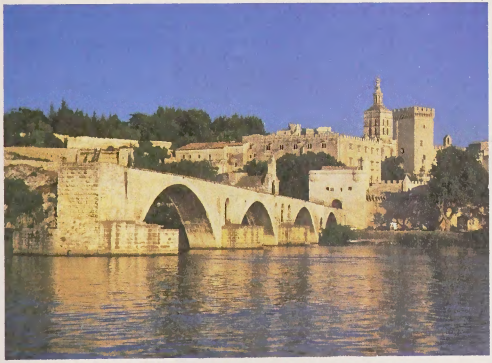

The Rhône River at Avignon, Fr., with the Saint-Bénézet Bridge in the foreground and the Papal Palace in the background.

History. Great cities attest the antiquity and the strength of people's interest in the region, which long ago was influenced by Celtic settlement and then by Roman domination. Brig, Sion, and Martigny in the Alpine section; Lausanne and Nyon on Lake Geneva; Lyon, at one of the major European crossways; and the Provençal cities of Nîmes, Arles, and Orange all contain evidence of their Roman past. From AD 1033 much of the region was controlled by the house of Savoy; ultimately, Valais, Geneva, and Vaud joined the Swiss Confederation, while Savoy itself became part of France. During the 14th and early 15th centuries, Avignon (located just north of the Rhône delta) was the residence of the popes of the Avignon papacy and antipopes of the Western Schism. The river, once a spearhead for the penetration of Mediterranean cultures and peoples into northern Europe, again became a routeway for invasion, when Allied armies followed it north after landing in southern France during World War II. (P.V./A.Di.)

SEINE RIVER

The Seine River, 485 miles (780 kilometres) long, with its tributaries drains an area of about 30,400 square miles (78,700 square kilometres) in northern France; it is one of Europe's great historic rivers, and its drainage network carries most of the French inland waterway traffic. Since the early Middle Ages it has been above all the river of Paris, and the mutual interdependence of the river and the city that was established at its major crossing points has been indissolubly forged. The fertile centre of its basin in the Île-de-France was the cradle of the French monarchy and the nucleus of the expanding nation-state and is still its heartland and metropolitan region.

Physical features. *Physiography.* The Seine rises at 1,545 feet (471 metres) above sea level on the Mont Tasselot in the Côte d'Or region of Burgundy but is still only a small stream when it traverses porous limestone country beyond Châtillon. Flowing northwest from Burgundy, it enters Champagne above Troyes and traverses the dry chalk plateau of Champagne in a well-defined trench. Joined by the Aube near Romilly, the river bears west to skirt the Île-de-France in a wide valley to Montereau, where it receives the Yonne on its left bank. This tributary is exceptional in rising beyond the sedimentary rocks of the Paris Basin on the impermeable crystalline highland of the Morvan, a northward extension of the Massif Central. Turning northwest again, the Seine passes Melun and Corbeil as its trenched valley crosses the Île-de-France toward Paris. As it enters Paris, it is joined by its great tributary the Marne on the right, and, after traversing the metropolis, it receives the Oise, also on the right. In its passage through Paris, the river has been trained and narrowed between riverside quays. Flowing sluggishly in sweeping loops, the Seine passes below Mantes-la-Jolie across Normandy toward its estuary in the English Channel. The broad estuary opens rapidly and extends for 16 miles below Tancarville to Le Havre; it experiences the phenomenon of the tidal bore, which is known as the *mascaret,* although continued dredging since 1867 has deepened the river so that the *mascaret* has gradually diminished.

The geologic background

From its source to Paris, the Seine traverses concentric belts of successively younger sedimentary rocks, infilling a structural basin, the centre of which is occupied by the limestone platforms of the Île-de-France immediately surrounding Paris. The rocks of this basin are inclined gently toward Paris at the centre and present a series of outward-facing limestone (including chalk) escarpments (*côtes*) alternating with narrower clay vales. The *côtes* are breached by the Seine and its tributaries, which have made prominent gaps. As they converge upon Paris, the trenchlike river valleys separate a number of islandlike limestone platforms covered with fertile, easily worked windblown soil (*limon*). These platforms have provided rich cereal-growing land from time immemorial and constitute the Île-de-France. The lower course of the Seine, below Paris, is directed in a general northwesterly direction toward the sea, in conformity with the trend of the lines of structural weakness affecting the northern part of the basin. The English Channel breaches the symmetry of the basin on its northern side, interrupting the completeness of the concentric zones. Still in the chalk belt, the river enters the sea.

The basin of the Seine presents no striking relief contrasts. Within 30 miles of its source the river is already below 800 feet, and at Paris, 227 miles from its mouth, it is only 80 feet above sea level. It is thus slow flowing and eminently navigable, the more so because its regime is generally so regular.

Hydrology. Most of the river basin is formed of permeable rocks, the absorptive capacity of which mitigates the risk of river floods. Precipitation throughout the basin is modest, generally 25 to 30 inches (650 to 750 millimetres), and is evenly distributed over the year as rain, with snow infrequent except on the higher southern and eastern margins. The Yonne—unique among the tributaries in being derived from impermeable, crystalline highlands, where there is also considerable winter snow—also has the greatest influence on the Seine's regime (flow) because of the great variability of its flow; but the Seine is the most regular of the major rivers of France and the most naturally navigable. Occasionally the summer level is considerably reduced (such as in the summers of 1947 and 1949), but the sandbanks that are so typical of the

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The Seine River along the Île Saint-Louis, Paris.

Loire do not appear. Low water is further masked by the regularization of the river that has been carried out to improve its navigability. Winter floods are rarely dangerous, but in January 1910 exceptionally heavy rainfall caused the river to rise above 28 feet at Paris, flooding the extensive low-lying quarters along its ancient meander loop (the Marais). To match this high level it is necessary to go back to February 1658; but in January 1924 and also in January 1955 the river again rose to more than 23 feet in Paris. The average flow at Paris is about 10,000 cubic feet (280 cubic metres) per second, as compared with the 1910 flood rate of about 83,000 and the 1947 and 1949 minimums of about 700.

The economy. The Seine, especially below Paris, is a great traffic highway. It links Paris with the sea and the huge maritime port of Le Havre. Rouen, although some 75 miles from the sea, was France's main seaport in the 16th century, but it was surpassed by Le Havre in the 19th century. Vessels drawing up to 10 feet (3.2 metres) can reach the quays of Paris. Most of the traffic, which chiefly consists of heavy petroleum products and building materials, passes upstream to the main facilities of the port of Paris at Gennevilliers. The lower Seine system is connected with that of the Rhine by way of the Marne, and the Oise links it with the waterways of Belgium. The links with the Loire waterway and with the Saône-Rhône, dating from the 17th and 18th centuries when connecting canals were built, are now of minor importance. The water of the Seine is an important resource for the riverine population. Large electric power stations, both thermal and nuclear, draw their cooling water from the river. In addition, half of the water used in the region around Paris, both for industry and for human consumption, and three-fourths of the water used in the region between Rouen and Le Havre, is taken from the river.

Links with other river systems

Development of the river. Although the regime of the Seine is relatively moderate, improvements have been considered necessary since the beginning of the 19th century. To improve navigation, the water level was raised by means of dams and by storage reservoirs in the basin of the Yonne River. Lake Settons (1858), originally designed for the flotation of wood, and Crescent (1932) and Chaumeçon (1934) reservoirs have proved useful in reducing floods as well as in ensuring a constant water supply in summer. Upstream from the basin four large storage reservoirs have been built since 1950 on the Yonne, Marne, and Aube, as well as on the Seine itself. These relatively shallow impoundments (averaging about 25 feet in depth) cover large areas. The Seine Reservoir, for example, covers some 6,175 acres (2,500 hectares), while the Marne Reservoir, with an area of about 11,900 acres, is the largest artificial lake in western Europe. Surrounded by woodland and countryside, these reservoirs have become bird sanctuaries and tourist attractions in a new nature reserve.

(A.E.Sm./M.Da.)

Central European drainage systems

DANUBE RIVER

The Danube is the second longest river of Europe after the Volga. It rises in the Black Forest mountains of western Germany and flows for some 1,770 miles (2,850 kilometres) to the Black Sea. Along its course, it passes through nine countries under six variations of its name. In Germany and Austria it is known as the Donau, in Slovakia as the Dunaj, in Hungary as the Duna, in Croatia, Serbia and Montenegro, and Bulgaria as the Dunav, in Romania as the Dunărea, and in Ukraine as the Dunay.

The Danube played a vital role in the settlement and political evolution of central and southeastern Europe. Its banks, lined with castles and fortresses, formed the boundary between great empires, and its waters served as a vital commercial highway between nations. The river's majesty has long been celebrated in music. The famous waltz *An der schönen, blauen Donau* (1867; *The Blue Danube*), by Johann Strauss the Younger, became the symbol of imperial Vienna. In the 21st century the river has continued its role as an important trade artery. It has been harnessed for hydroelectric power, particularly along the upper courses, and the cities along its banks—including the national capitals of Vienna (Austria), Budapest (Hungary), and Belgrade (Serbia and Montenegro)—have depended upon it for their economic growth.

Physical features. *Physiography.* The Danube's vast drainage of some 315,000 square miles (817,000 square kilometres) includes a variety of natural conditions that affect the origins and the regimes of its watercourses. They favour the formation of a branching, dense, deepwater river network that includes some 300 tributaries, more than 30 of which are navigable. The river basin expands unevenly along its length. It covers about 18,000 square miles at the Inn confluence, 81,000 square miles after joining with the Drava, and 228,000 square miles below the confluences of its most affluent tributaries, the Sava and the Tisza. In the lower course the basin's rate of growth decreases. More than half of the entire Danube basin is drained by its right-bank tributaries, which collect their waters from the Alps and other mountain areas and contribute up to two-thirds of the total river runoff or outfall.

Three sections are discernible in the river's basin. The upper course stretches from its source to the gorge, called the Hungarian Gates, in the Austrian Alps and the Western Carpathian Mountains. The middle course runs from the Hungarian Gates to the Iron Gate gorge in the Southern Romanian Carpathians. The lower course flows from the Iron Gate to the deltalike estuary at the Black Sea.

Three sections of the Danube

The upper Danube springs as two small streams—the Breg and Brigach—from the eastern slopes of the Black Forest mountains of Germany, which partially consist of limestone. From Donaueschingen, where the headstreams unite, the Danube flows northeastward in a narrow, rocky bed. To the north rise the wooded slopes of the Swabian and the Franconian mountains; between Ingolstadt and Regensburg the river forms a scenic canyonlike valley. To the south of the river course stretches the large Bavarian Plateau, covered with thick layers of river deposits from the numerous Alpine tributaries. The bank is low and uniform, composed mainly of fields, peat, and marshland.

At Regensburg the Danube reaches its northernmost point, from which it veers south and crosses wide, fertile, and level country. Shortly before it reaches Passau on the Austrian border, the river narrows and its bottom abounds with reefs and shoals. The Danube then flows through Austrian territory, where it cuts into the slopes of the Bohemian Forest and forms a narrow valley. In order to improve navigation, dams and protecting dikes have been built near Passau, Linz, and Ardagger. The upper Danube, some 600 miles long, has a considerable average inclination of the riverbed (0.93 percent) and a rapid current of two to five miles per hour. Depths vary from 3 to 26 feet (1 to 8 metres). The Danube swells substantially at Passau where the Inn River, its largest upstream tributary, carries more water than the main river. Other major tributaries in the upper Danube course include the Iller, Lech, Isar, Traun, Enns, and Morava rivers.

In its middle course the Danube looks more like a flatland river, with low banks and a bed that reaches a width of more than one mile. Only in two sectors—at Visegrád (Hungary) and the Iron Gate—does the river flow through narrow, canyonlike gorges. The basin of the middle Danube exhibits two main features—the flatland of the Little Alfold and the Great Alfold plains, and the low peaks of the Western Carpathians and the Transdanubian Mountains.

The Danube enters the Little Alfold plain immediately after emerging from the Hungarian Gates near Bratislava, Slovakia. There the streamflow slows down abruptly and loses its transporting capacity, so that enormous quantities of gravel and sand settle on the bottom. A principal result of this deposition has been the formation of two islands, one on the Slovak side of the river and the other on the Hungarian side, which combined have an area of about 730 square miles that support some 190,000 inhabitants in more than 100 settlements. The silting hampers navigation and occasionally divides the river into two or more channels. East of Komárno the Danube enters the Visegrád Gorge, squeezed between the foothills of the Western Carpathian and the Hungarian Transdanubian Mountains.



Vineyards along the Danube River in the Wachau region, Austria.
G. Hofmann—Superstock

The steep right bank is crowned with fortresses, castles, and cathedrals of the Hungarian Árpád dynasty of the 10th to 15th century.

The Danube then flows past Budapest and across the vast Great Alfold plain until it reaches the Iron Gate gorge. The riverbed is shallow and marshy, and low terraces stretch along both banks. River accumulation has built a large number of islands, including Csepel Island near Budapest. In this long stretch the river takes on the waters of its major tributaries—the Drava, the Tisza, and the Sava—which create substantial changes in the river's regime. The average runoff increases from about 83,000 cubic feet (2,400 cubic metres) per second north of Budapest to 200,000 cubic feet at the Iron Gate. The river valley looks most imposing there, and the river's depth and current velocity fluctuate widely. The rapids and reefs of the Iron Gate once made the river unnavigable until a lateral navigation channel and a parallel railway allowed rivercraft to be towed upstream against the strong current.

The Iron Gate

Beyond the Iron Gate the lower Danube flows across a wide plain; the river becomes shallower and broader, and its current slows down. To the right, above steep banks, stretches the tableland of the Danubian Plain of Bulgaria. To the left lies the low Romanian Plain, which is separated from the main stream by a strip of lakes and swamps. The tributaries in this section are comparatively small and



The Danube River basin and its drainage network.

account for only a modest increase in the total runoff. They include the Olt, the Siret, and the Prut. The river is again obstructed by a number of islands. Just south of Cernavodă, the Danube heads northward until it reaches Galaţi, where it veers abruptly eastward. Near Tulcea, some 50 miles from the sea, the river begins to spread out into its delta.

The river splits into three channels—the Chilia, which carries 63 percent of the total runoff; the Sulina, which accounts for 16 percent; and the Sfîntu Gheorghe (St. George), which carries the remainder. Navigation is possible only by way of the Sulina Channel, which has been straightened and dredged along its 39-mile length. Between the channels, a maze of smaller creeks and lakes are separated by oblong strips of land called *grinduri.* Most *grinduri* are arable and cultivated, and some are overgrown with tall oak forests. A large quantity of reeds that grow in the shallow-water tracts are used in the manufacture of paper and textile fibres. The Danube delta covers an area of some 1,660 square miles and is a comparatively young formation. About 6,500 years ago the delta site was a shallow cove of the Black Sea coast, but it was gradually filled by river-borne silt; the delta continues to grow seaward at the rate of 80 to 100 feet annually.

Hydrology. The different physical features of the river basin affect the amount of water runoff in its three sections. In the upper Danube the runoff corresponds to that of the Alpine tributaries, where the maximum occurs in June when melting of snow and ice in the Alps is the most intensive. Runoff drops to its lowest point during the winter months.

In the middle basin the phases last up to four months, with two runoff peaks in June and April. The June peak stems from that of the upper course, reaching its maximum 10 to 15 days later. The April peak is local. It is caused by the addition of waters from the melting snow in the plains and from the early spring rains of the lowland and the low mountains of the area. Rainfall is important; the period of low water begins in October and reflects the dry spells of summer and autumn that are characteristic of the low plains. In the lower basin all Alpine traits disappear completely from the river regime. The runoff maximum occurs in April, and the low point extends to September and October.

The river carries considerable quantities of solid particles, nearly all of which consist of quartz grains. The constant shift of deposits in different parts of the riverbed forms shoals. In the stretches between Bratislava and Komárno and in the Sulina Channel, draglines are constantly at work to maintain the depth needed for navigation. The damming of the river has also changed the way in which sediments are transported and deposited. Water impounded by reservoirs generally loses its silt load, and the water flowing out of the dam—which is relatively silt-free—erodes banks farther downstream.

The temperature of the river waters depends on the climate of the various parts of the basin. In the upper course, where the summer waters derive from the Alpine snow and glaciers, the water temperature is low. In the middle and lower reaches, summer temperatures vary between 71° and 75° F (22° and 24° C), while winter temperatures near the banks and on the surface drop below freezing. Upstream from Linz the Danube never freezes entirely, because the current is turbulent. The middle and lower courses, however, become icebound during severe winters. Between December and March, periods of ice drift combine with the spring thaw, causing floating ice blocks to accumulate at the river islands, jamming the river's course, and often creating major floods.

The winter freeze

The natural regime of river runoff changes constantly as a result of the introduction of stream-regulating equipment, including dams and dikes. The mineral content of the river is greater during the winter than the summer. The content of organic matter is relatively low, but pollution increases as the waters flow past industrial areas. The river's chemistry also changes as city sewage and agricultural runoff find their way into the river.

The economy. The Danube is of great economic importance to the nine countries that border it—Ukraine, Romania, Serbia and Montenegro, Croatia, Hungary, Bulgaria, Slovakia, Austria, and Germany—all of which variously use the river for freight transport, the generation of hydroelectricity, industrial and residential water supplies, irrigation, and fishing. The movement of freight is the most important economic use of the Danube, and such cities as Izmail, Ukraine; Galaţi and Brăila, Rom.; Ruse, Bulg.; Belgrade, Serbia, Serb.-Mont.; Budapest; Bratislava, Slvk.; Vienna; and Regensburg, Ger., are among the major ports. Since World War II, navigation has been improved by dredging and by the construction of a series of canals, and river traffic has increased considerably. The most important canals—all elements in a continentwide scheme of connecting waterways—include the Danube–Black Sea Canal, which runs from Cernovadă, Rom., to the Black Sea and provides a more direct and easily navigable link, and the Main–Danube Canal, completed in 1992 to link the Danube to the Rhine and thus to the North Sea.

The Danube has been tapped for power, mainly in its upper course. The process, however, has spread downstream. One of the largest hydroelectric projects—the Đerdap High Dam and the Iron Gate power station—was built jointly by Yugoslavia and Romania. Not only does the project produce hydroelectricity but it also makes navigable what was once one of the most difficult stretches on the river.

Dams and irrigation

Industrial use of Danube waters is made at Vienna, Budapest, Belgrade, and Ruse. The main irrigated areas are along the river in Slovakia, Hungary, Serbia and Montenegro, and Bulgaria. The river, however, has nearly become unfit for irrigation as well as for drinking water because of the great increase in pollutants; pollution has also diminished the once-rich fishing grounds, although some of the fish have moved to side lakes and swamps.

History. During the 7th century BC, Greek sailors reached the lower Danube and sailed upstream, conducting a brisk trade. They were familiar with the whole of the river's lower course and named it the Ister. The Danube later served as the northern boundary of the vast Roman Empire and was called the Danuvius. A Roman fleet patrolled its waters, and the strongholds along its shores were the centres of settlements, among them Vindobona (later Vienna), Aquincum (later Budapest), Singidunum (later Belgrade), and Sexantaprista (later Ruse).

During the Middle Ages the old fortresses continued to play an important role, and new castles such as Werfenstein, built by Charlemagne in the 9th century, were erected. When the Ottoman Empire spread from southeastern to central Europe in the 15th century, the Turks relied upon the string of fortresses along the Danube for defense. The Habsburg dynasty recognized the navigational potential of the Danube. Maria Theresa, queen of Hungary and Bohemia from 1740 to 1780, founded a department to oversee river navigation, and in 1830 a riverboat made a first trip from Vienna to Budapest, possibly for trading purposes. This trip marked the end of the river's importance as a line of defense and the beginning of its use as a channel of trade.

Regulated navigation on the Danube has been the subject of a number of international agreements. In 1616 an Austro-Turkish treaty was signed in Belgrade under which the Austrians were granted the right to navigate the middle and lower Danube. In 1774, under the Treaty of Küçük Kaynarca, Russia was allowed to use the lower Danube. The Anglo-Austrian and the Russo-Austrian conventions of 1838 and 1840, respectively, promoted free navigation along the entire river, a principle that was more precisely formulated in the Treaty of Paris of 1856, which also set up the first Danubian Commission with the aim of supervising the river as an international waterway. In 1921 and 1923, final approval of the Danube River Statute was granted by Austria, Germany, Yugoslavia, Bulgaria, Romania, Great Britain, Italy, Belgium, Czechoslovakia, Hungary, and Greece. The international Danube Commission was thus established as an authoritative institution with wide powers, including its own flag, the right to levy taxes, and diplomatic immunity for its members. It controlled navigation from the town of Ulm to the Black Sea and kept navigational equipment in good repair.

International control

During World War II, free international navigation along the course of the river was interrupted by the hostilities, and a consensus concerning the resumption of navigation was not reached until the Danubian Convention of 1948. The new convention provided for the Danubian countries alone to participate in a reconstituted Danube Commission; of these countries, only West Germany did not join the convention. (P.G.P.)

ELBE RIVER

The Elbe (Czech: Labe), one of the major waterways of central Europe, runs from the Czech Republic through Germany to the North Sea, flowing generally to the northwest. It rises on the southern side of the Krkonoše (Giant) Mountains near the border of the Czech Republic and Poland. The river makes a wide arc across Bohemia (northwestern Czech Republic) and enters eastern Germany about 25 miles (40 kilometres) southeast of Dresden. For the remainder of its course it flows through Germany. Above Hamburg the Elbe splits into two branches; these rejoin farther downstream, and the river then broadens into its estuary, the mouth of which is at Cuxhaven, where it flows into the North Sea.

The total length of the Elbe is 724 miles (1,165 kilometres), of which roughly one-third flows through the Czech Republic and two-thirds through Germany. Its total drainage area is 55,620 square miles (144,060 square kilometres). Major tributaries are the Vltava (Moldau), Ohře (Eger), Mulde, and Saale rivers, all of which join it from the left, and the Iser, Schwarze ("Black") Elster, Havel, and Alster rivers from the right.

Physical features. *Physiography.* The Elbe is formed by the confluence of numerous headwater streams in the Krkonoše Mountains a few miles from the Polish-Czech frontier. It flows south and west, forming a wide arc for about 225 miles in the Czech Republic to its confluence with the Vltava at Mělník and is joined 18 miles downstream by the Ohře. It then cuts to the northwest through the picturesque Elbe Sandstone Mountains, and, in a gorge four miles long, it enters Germany. Between Dresden and Magdeburg the Elbe receives many long tributaries, of which all except the Schwarze Elster are left-bank streams. These are the Mulde and the Saale and its tributaries—including the Weisse ("White") Elster, the Unstrut, and the Ilm. These left-bank tributaries rise in the Ore Mountains or the Thuringian Forest and form the drainage basin of the middle Elbe, with its geographic foci in Halle and Leipzig. Halle is on the Saale, just below the confluence of the Weisse Elster; Leipzig lies at the confluence of the Pleisse and the Weisse Elster. Below Magdeburg the Elbe receives most of its water from its right bank. Most of these tributaries rise in the uplands of Mecklenburg.

The middle Elbe

The river enters the North German Plain at Riesa, 25 miles below Dresden; below Riesa it meanders in a wide floodplain and has some abandoned loops. Dikes begin there and continue as far as the confluence of the Mulde. Between Wittenberg and Dessau the east–west valley floor narrows to five miles in width, and hilly land rises to the north (the Fläming Heath) and south. From Dessau to Magdeburg the floodplain widens, and dikes have been constructed continuously down to the sea. In its course below Magdeburg the floodplain is two miles wide down to the confluence with the Havel. The river keeps to the left of its floodplain and sometimes cuts into the low hills on its banks. Below the confluence with the Havel the river flows southeast–northwest; the floodplain widens and has distributaries and backwaters often flanked by low sandy hills (geest). Reclaimed salt marshes begin at Lauenburg. Above Hamburg—which the Elbe transverses in two arms, the Norder Elbe and the Süder Elbe—the floodplain is eight miles wide but narrows to four miles between the sandy geest of Schleswig-Holstein and the Lüneburg Heath.

Reclaimed salt marshes

The estuary proper of the Elbe (Unterelbe) extends from Hamburg to Cuxhaven, a distance of about 55 miles. It varies in width from one to two miles, but much of it is occupied by mud flats and sandbanks. The main channel is buoyed and dredged. At high tide the channel has a depth of some 53 feet (16 metres). The south or left bank is low and marshy and the river has sandbanks; the right bank is steep below Hamburg, but farther downstream there are marshes, diked and drained, that are intensively cultivated. The great port city of Hamburg grew up on the Alster River on low sandy hills above the marshes. The modern port facilities have spread to the low-lying south bank of the Elbe.

Hydrology. The flow of water in the Elbe varies considerably with the amount of precipitation and thawing in its drainage basin. At Dresden the discharge rate averaged 11,200 cubic feet (317 cubic metres) per second in the period 1931–75, but the rate varied from a minimum of 800 cubic feet to a maximum of 118,700. At Neu-Darchau, about 140 miles above the mouth, the discharge rate was 24,700 cubic feet per second in the period 1926–65, with extremes of 5,100 and 127,700. These great variations sometimes hinder navigation. Although there are dams on the upper Elbe in the Czech Republic and at Geesthacht, Ger., and large dams have been built on the Vltava and on

A.G.E. FotoStock



The Kiel Canal, which runs from the mouth of the Elbe River to the Baltic Sea, at Kiel, Ger.

Elbe, Oder, and Vistula river basins
Navigable rivers
Canals
Swamps and marshes
Elevation
meters
feet
500
1,640
200
656
100
328
NORTH SEA
BALTIC SEA
Gulf of Gdansk
Vistula Lagoon
Szczecin Lagoon
Kaliningrad
RUSSIA
LITHUANIA
BELARUS
UKRAINE
POLAND
GERMANY
CZECH REPUBLIC
SLOVAKIA
HUNGARY
AUSTRIA
FRANCE
NETHERLANDS
PRUSSIAN LOWLAND
MASURIAN LAKELAND
SANDOMIERZ BASIN
TRIPET MARSHES
ELBE
ODER
VISTULA
Augustów Canal
Oginski Canal
Bydgoszcz Canal
Oder-Spree Canal
Oder-Havel Canal
Havel Canal
Berlin-Havel Canal
Elbe-Lübeck Canal
Elbe-Seitenkanal
Mittelland Canal
Dortmund-Ems Canal
Rhine-Main-Danube Canal
Gdansk
Elbląg
Malbork
Olsztyn
Grudziądz
Toruń
Włocławek
Płock
Warsaw
Bydgoszcz
Poznań
Konin
Łódź
Kalisz
Wrocław
Opole
Katowice
Częstochowa
Radom
Lublin
Sandomierz
Przemyśl
Rzeszów
Tarnów
Kraków
Nowy Sącz
Zamość
Lviv
Ternopil
Ivano-Frankivsk
Chernivtsi
Uzhhorod
Berlin
Frankfurt
Cottbus
Eisenhüttenstadt
Wittenberge
Brandenburg
Potsdam
Dessau
Magdeburg
Schönebeck
Genthin
Halle
Leipzig
Dresden
Chemnitz
Zwickau
Plauen
Erfurt
Gera
Jena
Weimar
Eisenach
Kassel
Hannover
Minden
Wolfsburg
Celle
Lüneburg
Uelzen
Hamburg
Lübeck
Bremen
Cuxhaven
Osnabrück
Münster
Emden
Wilhelmshaven
Frankfurt am Main
Mannheim
Karlsruhe
Stuttgart
Ulm
Nuremberg
Regensburg
Passau
Linz
Brno
Ostrava
Bratislava
Budapest
Miskolc
Debrecen
Szeged
Pécs
Győr
Maribor
Graz
Salzburg
Innsbruck
Munich
Augsburg
Strasbourg
Metz
Nancy
Reims
Lille
Amiens
Rouen
Le Havre
Caen
Paris
Orléans
Tours
Nantes
Dijon
Lyon
Grenoble
Marseille
Nice
Toulouse
Montpellier
Bordeaux
Limoges
Clermont-Ferrand
Geneva
Zürich
Milan
Turin
Genoa
Bologna
Florence
Rome
Naples
Venice
Trieste
Zagreb
Ljubljana
Sarajevo
Belgrade
Novi Sad
Timişoara
Cluj-Napoca
Iaşi
Chişinău
Odesa
Dnipropetrovsk
Kharkiv
Donetsk
Luhansk
Kyiv
Dnipro
Zaporizhzhya
Simferopol
Sevastopol
Kerch
Volgograd
Saratov
Samara
Kazan
Nizhniy Novgorod
Moscow
Tula
Ryazan
Smolensk
Bryansk
Kursk
Belgorod
Voronezh
Tambov
Penza
Ulyanovsk
Tolyatti
Orenburg
Ufa
Perm
Yekaterinburg
Chelyabinsk
Magnitogorsk
Kostanay
Petropavlovsk
Omsk
Tyumen
Novosibirsk
Barnaul
Kemerovo
Krasnoyarsk
Irkutsk
Bratsk
Ulan-Ude
Chita
Khabarovsk
Vladivostok
Yuzhno-Sakhalinsk
Sapporo
Hokkaido
Honshu
Kyushu
Shikoku
Osaka
Kobe
Nagoya
Kyoto
Hiroshima
Fukuoka
Nagasaki
Kagoshima
Okinawa
Taipei
Taiwan
Hong Kong
Guangzhou
Shenzhen
Xiamen
Fuzhou
Shanghai
Nanjing
Hangzhou
Ningbo
Wuhan
Changsha
Nanchang
Guiyang
Kunming
Chongqing
Chengdu
Xi'an
Lanzhou
Urumqi
Turpan
Hami
Dunhuang
Golmud
Lhasa
Xining
Yinchuan
Hohhot
Baotou
Taiyuan
Shijiazhuang
Tianjin
Beijing
Shenyang
Changchun
Harbin
Qiqihar
Mudanjiang
Jilin
Dalian
Qingdao
Yantai
Weihai
Zhengzhou
Luoyang
Xuzhou
Lianyungang
Yangzhou
Suzhou
Wuxi
Changzhou
Nantong
Hefei
Anqing
Jiujiang
Yichang
Xiangfan
Shiyan
Baoji
Tianshui
Lanzhou
Golmud
Ürümqi
Turpan
Hami
Dunhuang

the Saale in the Thuringian Forest, these are not sufficient to control the water level of the Elbe.

The lower course of the Elbe is tidal as far as the dam at Geesthacht, above Hamburg, where the river flow periodically reverses its direction. The average tide at Hamburg is about eight feet. However, during storms the water may rise much higher, occasionally even flooding parts of the city.

Traffic on the Elbe

The economy. By means of the Elbe and its connecting waterways, vessels from Hamburg can navigate to Berlin, the central and southern sections of eastern Germany, and the Czech Republic. The Mittelland Canal, a short distance below Magdeburg, runs westward about 200 miles to the Dortmund–Ems Canal, carrying barges of up to 1,000 tons to the German industrial cities of Osnabrück, Hannover, Salzgitter, Hildesheim, Peine, and Wolfsburg and connecting with the Weser and Rhine rivers. The Elbe–Havel Canal carries traffic from Magdeburg eastward to the network of waterways around Berlin and farther on to Poland. The Kiel Canal runs from the mouth of the Elbe to the Baltic Sea, and the Elbe–Lübeck Canal, starting at Lauenburg, also runs to the Baltic, following an older (14th-century) canal. Another canal connects the lower Elbe with Bremerhaven on the Weser River. The Elbe itself is navigable for 1,000-ton barges as far as Prague through the Vltava. In eastern Germany it serves the river ports of Magdeburg, Schönebeck, Aken, Dessau, Torgau, Riesa, and Dresden, carrying bituminous coal, lignite, coke, metal, potash, grain, and piece goods. Although Hamburg lies far upstream from the mouth of the Elbe, it is one of the largest seaports in Europe; a six-line railway tunnel and a multilane road tunnel under the Elbe there are important links in trans-European traffic flows.

History. The basin of the Elbe has been settled since prehistoric times. Until the Middle Ages the river was the western boundary of the area inhabited by the northern Slavs. In the 12th century the Germans began to colonize the lands east of the Elbe and along the Baltic Sea. In World War II a point on the Elbe near Torgau was the meeting place of the U.S. and Soviet armies. From the end of the war until 1990, the river formed part of the demarcation between East and West Germany.

Hamburg

The city of Hamburg dates from the early 9th century AD. Together with Lübeck, Hamburg established the Hanseatic League in 1241. Today it is Germany's second largest city, surpassed only by Berlin. Another ancient city on the Elbe is Magdeburg, which in the early 9th century was a trading post on the border between the Germans and the Slavs. In the 13th century it was a flourishing commercial city and an important member of the Hanseatic League. Today it is the largest inland harbour of eastern Germany. The other chief city of the Elbe is Dresden, founded about 1200. During the 18th century Dresden developed into a great centre of the fine arts, known as "Florence on the Elbe." Its beautiful architecture, almost completely destroyed during World War II, has been partially rebuilt. Other towns of historical interest along the Elbe include Wittenberg, the birthplace of the Protestant Reformation, and Meissen, which became famous for the manufacture of porcelain. (H.F./F.G.)

ODER RIVER

The Oder River, a vital economic artery in east central Europe, runs through the western portions of Poland and has considerable contemporary regional importance. It is one of the most significant rivers in the catchment basin of the Baltic Sea, second only to the Vistula in discharge and length. For the first 70 miles (112 kilometres) from its source, it passes through the Czech Republic. For a distance of 116 miles in its middle reach, it constitutes the boundary between Poland and Germany before reaching the Baltic Sea via a lagoon north of the Polish city of Szczecin. Called the Odra in Polish and Czech and the Oder in German, the river is an important waterway, navigable throughout most of its length. It forms a link, by way of the Gliwice Canal, between the great industrialized areas of Silesia (Śląsk), in southwestern Poland, and the trade routes of the Baltic Sea and beyond. The Oder is connected with the Vistula, Poland's largest river, by means of a water route utilizing the Warta and Noteć rivers, together with the Bydgoszcz Canal, and is tied in with the waterway system of western Europe by way of the Oder–Spree and Oder–Havel canals in eastern Germany.

The total length of the Oder River is 531 miles (854 kilometres), 461 miles of which lie in Poland. The total watershed area has been calculated at 46,000 square miles (119,000 square kilometres), of which about 90 percent is in Polish territory. The mean elevation of the Oder basin is 535 feet (163 metres) above sea level. From the river's source and over the greater part of its course, the Oder flows in a generally southeast–northwest direction; only from the junction with the Neisse (Polish: Nysa Łużycka) River does the northward trend toward the Baltic commence. The principal left-bank tributaries are the Opava of the Czech Republic and the Osobłoga, Nysa Kłodzka, Oława, Ślęza, Bystrzyca, Kaczawa, Bóbr, and Neisse of Poland; from the east the main tributaries are the Olše of the Czech Republic and the Kłodnica, Mała Panew, Strobrawa, Widawa, Barycz, Obrzyca, Warta, Myśla, and Ina of Poland. From the junction with the Opava, the Oder is navigable for a distance of some 475 miles for 220 to 230 days of the year. Towns of particular importance along the Oder are Ostrava in the Czech Republic, Frankfurt in Germany, and Racibórz, Opole, Brzeg, Wrocław, Nowa Sól, and Szczecin in Poland.

Source

Physical features. *Physiography.* The Oder starts its course in the Czech Republic, at an altitude of nearly 2,100 feet in the Hrubý Jeseník Mountains. Initially it runs as a mountain stream with a steep gradient that progressively lessens until the river reaches the floor of the structural depression called the Moravian Gate; from there the Oder continues its course in a wide valley. After receiving the Olše River, the Oder enters Poland and makes its way as a river that in a characteristic manner alternates between following ancient east–west stream valleys of glacial origin and crossing gaps cut in the intervening uplands. Where the Oder takes advantage of these preexisting valleys, it reaches widths as great as six miles or more, while in gaps it narrows to about a mile. Near Kozle the Gliwice Canal enters the Oder, and from there as far as Brzeg Dolny, a short way downstream from Wrocław, the river has a navigable channel controlled by locks. From Brzeg Dolny downstream until the final outflow into the Szczecin Lagoon, the river channel is fully improved. Beginning with the confluence with the Neisse River and continuing to just above Szczecin, the Oder becomes the borderline between Poland and Germany. In this part of the valley the Oder–Spree and the Oder–Havel canals branch off to the west. Farther downstream the Oder valley contains numerous cross branches and parallel channels. About 50 miles from its outflow into the Baltic, the Oder splits into two main branches; the left canalized branch, called the Western Oder, passes through Szczecin and enters the Szczecin Lagoon directly, while the right branch, the Eastern Oder (in its final section called the Regalica), passes east of Szczecin via the large Lake Dąbie and then also enters the Szczecin Lagoon.

Hydrology. The Oder has a limited flow volume; its mean ratio of outflow to precipitation is the lowest among the rivers flowing into the Baltic. During low-water periods, in summer and autumn, the river is fed from storage reservoirs built in the upper tributaries. The mean water depth in the Oder channel is three feet, and the mean velocity is three feet per second. In summer the upper reaches of the Oder system are flooded by heavy precipitation, while in spring the middle and lower reaches suffer from meltwater floods. Flow volume varies with the amount of precipitation. In the period 1951–80, for example, the discharge rate of the Oder's upper course averaged 1,560 cubic feet (145 cubic metres) per second, with extremes of 150 and 31,430; during that same period in the middle course the average was 18,820 cubic feet per second, with extremes of 5,510 and 76,630. The ice cover on the river lasts up to 40 days per year. As is the case with many of the world's great rivers flowing through heavily industrialized regions, the Oder's waters have become heavily polluted; of the fish that are still found in the river, the most common are bream and eel.



Barge traffic on the Oder River at Wrocław, Pol.
Ginette Laborde, Paris Charenton, Fr.

Improvements

The first hydraulic works—embankments and other structures for flood prevention—were started in the Oder valley as early as the 12th century; spillway dams built in the 13th century were in operation until the 18th century, when work was initiated on channel straightening by means of excavated cuts. Improvement of the straightened part of the Oder Channel was for the most part completed around 1900 (although final improvements were not made until after World War II), while control works in the middle and lower reaches were carried out in the interwar period.

The economy. The Oder River is an important element in the Polish economy, supplementing the heavily overburdened railway and highway systems that link the highly industrialized regions of the south with the largest Polish seaport, Szczecin, at the Oder's Baltic mouth. The river carries about 10 percent of the total tonnage handled by the port. The Oder is also used by the barges of eastern Germany, which travel over a system of navigable canals that connect the Oder with the central European waterway network. A system of navigable canals connects the Oder with the Vistula, Poland's largest river, and also with the rivers of the eastern portion of the country and the waterway systems of Belarus, Ukraine, and Russia. This creates the possibility that the entire system may evolve into an all-water commercial route for transporting commodities from west to east and from east to west.

History. Because of its geographic situation, the Oder was, in ancient times, of major importance as the zone where people inhabiting southern and northern Europe came into contact with each other and exchanged cultural values. The first agricultural population arrived from the south after passing the Moravian Gate, which separates the Sudeten ranges from the Carpathian Mountains. Along the middle reach of the Oder there developed the pre-Lusatian and the Lusatian cultures (of the Bronze Age), which greatly affected the later evolution of the Slav population. In the area surrounding the Oder estuary, there was a mutual interpenetration by Scandinavian, Germanic, and Slav cultures. Finally, in the 9th and 10th centuries, the Polish state developed between the Oder and the Vistula. In the 13th century the German expansion dislodged Poland eastward, away from the Oder basin. But, on the basis of the 1945 Potsdam Conference between the Soviet Union, the United States, and Great Britain, the Polish nation returned to its former lands bordering the Oder River.

VISTULA RIVER

The Vistula (Polish: Wisła) is the largest river of Poland and of the drainage basin of the Baltic Sea. With a length of 651 miles (1,047 kilometres) and a drainage basin of some 75,100 square miles (194,500 square kilometres), it is a waterway of great importance to the nations of eastern Europe; more than 85 percent of the river's drainage basin, however, lies in Polish territory. The Vistula is connected with the Oder drainage area by the Bydgoszcz Canal. Eastward the Narew and Bug rivers and the Dnieper–Bug Canal link it with the vast inland waterway systems of Belarus, Ukraine, and Russia. The source of the Vistula is found about 15 miles south of Bielsko-Biała on the northern slopes of the western Beskid range, in southern Poland, at an altitude of 3,629 feet (1,106 metres). It flows generally from south to north through the mountains and foothills of southern Poland and across the lowland areas of the great North European Plain, ending in a delta estuary that enters the Baltic Sea near the port of Gdańsk. The average elevation of the Vistula basin is 590 feet above sea level; the mean river gradient is 0.10 percent, and the mean velocity in the river channel amounts to 2.6 feet per second. In addition to Poland's capital city, Warsaw, a number of large towns and industrial centres lie on the banks of the Vistula. These include Kraków, which was Poland's capital from the 11th century to the close of the 16th, Nowa Huta, Sandomierz, Płock, Toruń, Malbork, and Gdańsk. Numerous centres of tourism and recreation as well as many health resorts flank the Vistula valley. Here and there along the river rise the ruins of medieval strongholds, some of which have been restored.

Source

Physical features. *Geology.* The present spatial pattern of the Vistula's tributary system and delta is the result of the changes in relief that occurred during the second half of the Tertiary and the Quaternary periods—*i.e.*, since about 30 million years ago. In the mountains the Vistula valley assumed its present shape much earlier and still reveals the way in which it has adapted itself to the geologic structure; in the lowland, on the other hand, the valley evolution was contingent on the history of the successive glaciations and, in particular, on changes during the interglacial period in which the Vistula abandoned its previous west–east valley and established its present northward course. The terminal part of the lower Vistula was finally stabilized in postglacial times, after the formation of the Baltic Sea.

A characteristic feature of the Vistula drainage basin is its asymmetry, with a predominance of right-bank over left-bank tributaries. This is the result of the general slant of the North European Plain in a northwesterly direction, which enabled the more powerful rivers of the Baltic drainage area to intercept the glacial streams flowing farther east.

Physiography. The course of the Vistula consists of three principal sections delineated by the San and Narew rivers, the two most prominent tributaries. The upper reach extends from the source to where the San joins its parent river near Sandomierz; its length is about 240 miles. The middle reach, from the mouth of the San to that of the Narew, below Warsaw, is about 170 miles long. Finally, the lower reach, extending to the Baltic, covers 240 miles from the mouth of the Narew to the mouth of the estuary into the Gulf of Gdańsk.

The upper course

In its upper course the Vistula is a mountain stream with a steep gradient of up to 5 percent. Its main sources are the Czarna Wiselka and the Biała Wiselka, two brooks that meet to form the Mała Wisła ("Small Vistula"), which then flows northward. Some 25 miles farther on, the river gradient decreases suddenly to some 0.04 percent; from there, after turning eastward, the Vistula enters Lake Goczałkowice, an artificial storage basin built in 1955. Upon exiting the lake, the Vistula assumes the character of a lowland stream, with its gradient decreasing to 0.03–0.02 percent in the middle reaches and to 0.02–0.002 percent in its final stages. At a distance of 65 miles from the source, the Vistula is joined by the Przemsza River, a left-bank tributary, after which—for 585 miles—it is navigable. After the Sola and Skawa—two right-bank tributaries—join the river, the Vistula forces its way through a gap carved through a range of hills just before the city of Kraków. Channel improvements to this section have deprived the Vistula of much of its original character: several spillway steps have been constructed, creating a channel navigable by 300-ton barges. After passing through Kraków the Vistula turns to the east and, later, northeastward, crossing the wide Sandomierz Basin, where the valley is entered successively by the left-bank tributaries Szreniawa, Nida, Czarna, and Koprzywianka and from the right by the rivers Raba, Dunajec, Wisloka, and San.

The inflow of the San River marks the beginning of the middle reaches of the Vistula, which then turns northward, breaching another gap through an upland area. In the course of its middle reaches the Vistula absorbs, from the left, the Radomka and Pilica and, from the right, the rivers Wieprz, Wilga, Świder, and Narew. Below the confluence with the Narew, where the lower reach of the river starts, the Vistula turns first to the west and then, after receiving the Bzura, a left-bank tributary, in a northwesterly direction; meanwhile from the right, the Skrwa and Drwęca join the river. In part of the valley, from the mouth of the Wieprz River to Toruń, the natural, untamed character of the Vistula predominates.

There the river runs in a channel 2,000 to 4,000 feet wide, practically devoid of controlling structures; in parts the valley reaches widths up to six to nine miles, with the banks often 200 to 330 feet high. The low gradient of the river channel and abundant sandbanks render navigation difficult; in spring, when the ice cover breaks up and floats downstream, dangerous ice dams may form, causing the flooding of surrounding areas and often destroying embankments and bridges. A spillway step constructed at Włocławek in 1968 initiated a series of improvements that continued through the 1980s.

From Toruń to its entry into the Baltic, the Vistula has been turned into a fully improved waterway. The 19th-century Bydgoszcz Canal, following an ancient glacial valley, links the Vistula with the Oder, the second largest of Polish rivers. Also near Bydgoszcz the Vistula, having received a left-bank tributary in the Brda, turns northeastward in its third gap section, cut through the Pomeranian highlands. Above Grudziądz the river finally turns northward to approach the Baltic. After receiving three further tributaries—the Osa from the right and the Wda and the Wierzyca from the left—the Vistula enters Żuławy Wiślane, its delta area, renowned for its splendidly fertile soils. Żuławy is a forestless plain, partly below sea level, threaded by the Vistula and its branches, together with a great number of canals and drainage ditches. Some of the local embankments and dikes date to the 13th century. During World War II a great part of Żuławy was flooded, but improvements were made in the postwar years.

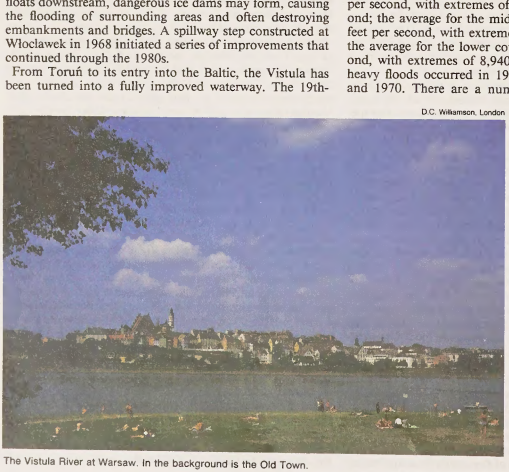
The delta region

In the past the Vistula crossed its delta and entered the sea by two or more branch channels, notably the Nogat, which issued into the Vistula Lagoon, and the Leniwka (now called the Martwa Vistula), which followed the true Vistula channel to the Gulf of Gdańsk. Improvements, the ultimate aim of which was to control the Vistula's outlet to the sea and make the entire delta region economically productive, were initiated at the end of the 19th century: first, a cut toward the open sea was excavated near Świbno to facilitate floodwater runoff and the removal of debris and ice carried by the river; later, all lateral watercourses were separated by locks, rendering them navigable, with controlled flows; the Świbno cut was extended into the open sea by lengthening the controlling embankments. This last change was intended to prevent the accumulation at the river mouth of the more than two million tons of sediment carried down annually by the Vistula.

Hydrology. Climatic variations in the Vistula basin cause a diversity in runoff and hence marked oscillations in the water level of the river, which averages 12 feet in the upper, 25 feet in the middle, and up to 33 feet in the lower reaches. Protracted low-water periods, lasting from late summer well into spring, are frequent. These hamper or entirely interrupt navigation. Spring floods caused by melting snow and ice in the whole drainage basin and summer floods resulting from heavy rains in the foothill and mountain regions are common features. During the period 1951–80 the mean flow of the upper course of the Vistula averaged about 2,200 cubic feet (62 cubic metres) per second, with extremes of 410 and 52,620 feet per second; the average for the middle course was about 20,900 feet per second, with extremes of 3,810 and 199,530; and the average for the lower course was 38,500 feet per second, with extremes of 8,940 and 276,870. Exceptionally heavy floods occurred in 1924, 1934, 1947, 1960, 1962, and 1970. There are a number of storage reservoirs in

The water level

D.C. Wilkamson, London



The Vistula River at Warsaw. In the background is the Old Town.

the valleys of the mountain tributaries that are intended to counteract excessive floods. Some newer, larger storage basins have been built.

Usually ice forms on the surface of the Vistula in the first half of January, breaking up toward the end of February. In the upper and lower reaches the duration of the ice sheet is from 20 to 40 days, in the middle reach 40 to 60 days, and in the estuary section up to 20 days.

The quality of the Vistula's waters is affected by water-management structures such as dams and hydroelectric plants, by the discharge of municipal and industrial wastewater, and by agricultural and storm runoff. Although the upper reaches of the river remain relatively pure, the lower portions of the Vistula, in common with similar stretches of many of the great rivers of the world, exhibit a high degree of pollution.

Temperature regime

The mean annual temperature of the Vistula water is 46° F (8° C) in the upper reaches and 49° F (9° C) in the middle and lower reaches; in the middle and lower parts of the river the water is some 4° F (2° C) warmer than the mean annual air temperature of Poland. In winter the water temperature is 36° to 37° F (2° to 3° C); in summer it varies from 54° to 59° F (12° to 15° C). In river sections that are thermally affected by nearby industries, however, as in the regions of Kraków, Warsaw, and Włocławek, the water temperature is apt to be as much as 11° to 18° F (6° to 10° C) or even higher.

Plant and animal life. Higher-growth aquatic plant species most often encountered in the Vistula valley are, among plants submerged in the water, arrowhead (*Sagittaria sagittifolia,* variety *vallisinfolia*); among plants with floating leaves, the water lily (*Nuphar luteum*); and, among air-growing plants, sweet flag (*Acorus calamus*).

More than 40 kinds of fish exist in the Vistula. In the upper reach, turbot is the most common, with bream in the middle and lower reaches, and, in the waters of the estuary, salmon trout and vimba vimba. Species penetrating the river from the Baltic are found only sporadically.

The economy. The Vistula is connected with the Oder River by the Brda River, the Bydgoszcz Canal, and the Notec and Warta rivers; and in 1960 the Soviet Union, East Germany, and Poland agreed to establish permanent shipping lines along this route. In 1963 a canal was opened to avoid the natural hazards at the confluence of the Vistula and the Narew, improving the links between the Vistula and the waterways system to the east.

Despite the Vistula's potential role as a transport link between the heavy industrial centres of southern Poland and the Baltic ports, navigational hazards have restricted its traffic. Nevertheless, attracted by water supply and by the possibilities of cheap transport rates for bulk materials, a number of large industrial projects have sprung up along the Vistula.

History. The Vistula played a prominent part in the ancient history of Poland. Since early Stone Age times the river served both as a trade route and as a means of expansion, from both north and south, for various peoples and cultures. Initially, raw materials and flint tools journeyed northward, while amber was sent to the south. By the time of the Roman Empire, the Vistula was one of the principal trade routes leading into central Europe; and from this period date the first historical references—by the classical geographers Pliny, Tacitus, and Ptolemy—to the Vistula and the Slav tribes living along its banks.

Medieval trade

Much later, in the early period of the Polish state (10th–13th century), the most important goods shipped over the Vistula route were salt, timber, grain, and building stone. The most intensive development of the Vistula as a trade route came from the 15th to 18th century, during which period a variety of hydraulic structures were put up, as well as embankments to provide flood protection. Many granaries and storehouses, built in the 14th century, line the banks of the Vistula. At the end of the 18th century, the partition of Poland between Prussia, Austria, and Russia put an end to the economic importance of the Vistula. Minor navigation improvements were undertaken only locally, in Prussia and in Austria. The major 19th-century improvements in the region of the delta and the construction of the Bydgoszcz Canal have been mentioned above. From 1920 to 1939 very little was done to improve the river channel. It was only after World War II that concerted efforts were undertaken to restore the Vistula to its historic function as a navigable waterway. This was done by the construction of a number of storage reservoirs and spillway dams in the river and its tributaries: the purpose was to take advantage of the river's hydroelectric potential and, at the same time, to adapt the channel to the travel of freight barges of 600- to 1,000-ton capacity.

A number of institutions are concerned with research on the Vistula and with keeping the waterway in operation. The highest authority coordinating activities in the field of research and deciding on technical expenditures and on navigational improvements is the Ministry of Environment Protection and Natural Resources. In addition, hydrologic measurements and investigations as well as engineering studies are carried out by the Institute for Meteorology and Water Management. (W.Pa./Je.P.)

Eastern European drainage systems

DNIEPER RIVER

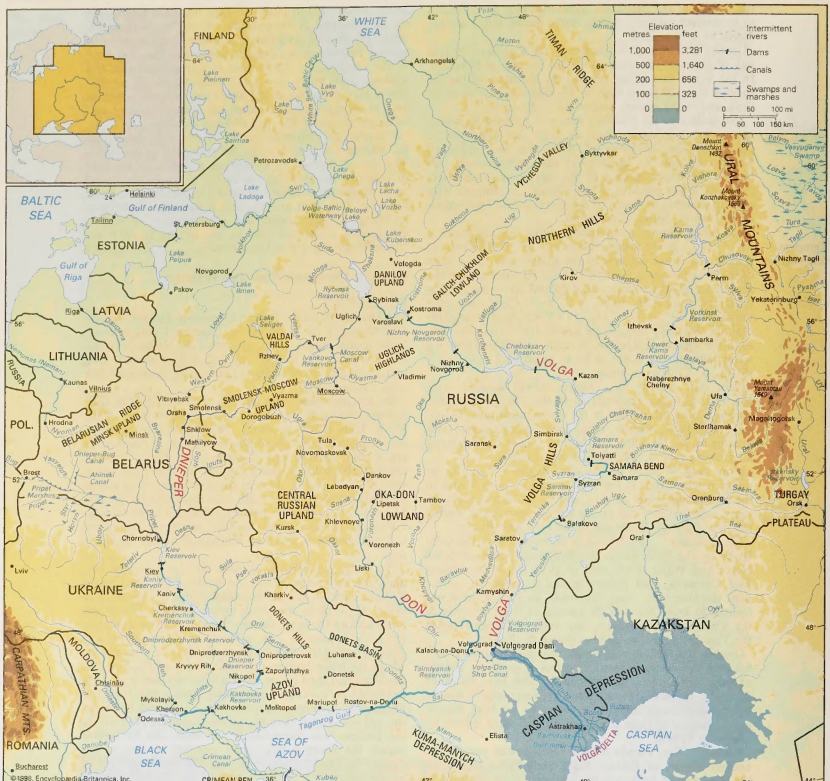
The Dnieper (Russian: Dnepr; Ukrainian: Dnipro; Belarusian: Dynapro; the Borysthenes of ancient Greek authors) is the fourth longest in Europe, after the Volga, Danube, and Ural rivers. It is 1,367 miles (2,200 kilometres) long and drains an area of about 195,000 square miles (505,000 square kilometres).

The Dnieper rises at an altitude of about 720 feet (220 metres) in a small peat bog on the southern slope of the Valdai Hills of Russia, about 150 miles west of Moscow, and flows in a generally southerly direction through western Russia, Belarus, and Ukraine to the Black Sea. For the first 300 miles, it passes through the Smolensk *oblast* (province) of Russia, first to the south and then to the west; near Orsha it turns south once more and for the next 370 miles flows through Belarus. Finally, it flows through Ukrainian territory: south to Kiev, southeast from Kiev to Dnipropetrovsk, and then south-southwest to the Black Sea.

The Dnieper watershed includes the Volyn-Podilsk Upland, the Belarusian Ridge, the Valdai Hills, the Central Russian Upland, and the Smolensk-Moscow Upland. The centre of the basin consists of broad lowlands. Within the forest area and to some extent within the forest steppe area, the basin is covered with morainic and fluvioglacial deposits; on the steppe it is covered with loess. In some places, where the basin borders upon the basins of the Bug and the Western Dvina rivers, there is a flat swampy area. This facilitated the cutting of connecting water routes from the Dnieper to neighbouring rivers even in ancient times. At the end of the 18th century and the beginning of the 19th, the Dnieper was connected to the Baltic Sea by several canals: the Dnieper–Bug Canal, running by way of the Pripet, Bug, and Vistula rivers; the Ahinski Canal by way of the Pripet and the Neman; and the Byarezina water system by way of the Byarezina and the Western Dvina. These canals later became obsolete.

Three sections

Physical features. *Physiography.* The Dnieper is customarily divided into three parts: the upper Dnieper as far as Kiev, the middle Dnieper from Kiev to Zaporizhzhya (Ukraine), and the lower Dnieper from Zaporizhzhya to the mouth. The basin of the upper Dnieper is mainly within a forest area where peat-podzolic soils predominate (replaced in the southern portion of the upper course by podzolized gray forest soils). The upper Dnieper is characterized by excessive moisture and great swampiness. The river network is well developed in this area, where about four-fifths of the basin's annual runoff forms and the longest tributaries with the greatest runoff (the Byarezina, Sozh, Pripet, Tetriv, and Desna) flow. The basin of the middle Dnieper is in a forest steppe area with black earth. Forests stand in the watersheds and along the river valleys. The river network is less dense there, and the rivers carry comparatively less water. The principal tributaries of the middle Dnieper are the Ros, Sula, Pesl, Vorskla, and Samara. The lower Dnieper basin lies within the Black Sea Lowland, in the black-soil steppe area, which has now been completely plowed up. The grassy steppe vege-


Elevation
metres
feet
1,000
3,281
500
1,640
200
656
100
329
0
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Intermittent rivers
Dams
Canals
Swamps and marshes
0 50 100 mi
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FINLAND
WHITE SEA
TIMAN RIDGE
Arkhangelsk
Petrozavodsk
Lake Peipsi
Lake Onega
Lake Ladoga
Lake Vyg
Lake Saima
Lake Vygozero
Lake Lacha
Lake Vozhe
Lake Kubenskoe
Lake Beloye
Lake Kulikovo
Lake Sviatoe
Lake Seliger
Lake Ilmen
Lake Pskovskoye
Lake Peipus
Lake Lubanas
Volga-Baltic Waterway
Mezen
Vashka
Pinega
Northern Dvina
Vychegda
Sukhona
Yug
Yuzha
Luza
Sysola
Kama
Vyatka
Ukhta
Vym
Pechora
VYCHEGDA VALLEY
Bytyvkar
URAL MOUNTAINS
Mount Narodnaya 1,894
Mount Konzhakovskiy Kamen 1,569
Mount Denezhkin Kamen 1,492
Vishera
Kosva
Sosva
Lozva
Tura
Tavda
Iset
Pyshma
Kama Reservoir
Votkinsk Reservoir
Chusovaya
Nizhny Tagil
Yekaterinburg
Perm
Kirov
NORTHERN HILLS
BALTIC SEA
Gulf of Finland
Helsinki
Tallinn
St. Petersburg
ESTONIA
Gulf of Riga
Riga
LATVIA
Pskov
Novgorod
Volkhov
Msta
Mologa
Sheksna
Rybinsk Reservoir
Rybinsk
Kostroma
Uglich
Yaroslavl
Volga
Vetluga
Unzha
Kerzhenets
Vetluga
GALICH-CHUKHLOMA LOWLAND
DANILOV UPLAND
Vologda
Sukhona
Kubenskoe
Nizhny Novgorod Reservoir
Cheboksary Reservoir
Lower Kama Reservoir
Belaya
Ufa
Izhevsk
Kambarka
Naberezhnyye Chelny
Mount Yamantau 1640
Magnitogorsk
Sterlitamak
Ural
Ufa
Tvertsa
Tvertsa Reservoir
Tver
VALDAI HILLS
UGLICH HIGHLANDS
Nizhny Novgorod
Vladimir
Kazan
VOLGA
Kama Reservoir
Cheboksary Reservoir
Chebotarikha
Kineshma
Klyazma
Moskva
Moscow
Moscow Canal
Ivankovo Reservoir
Dubna
Volga-Moscow Canal
Vazuza
Gzhat
Ugra
Oka
Protva
Nara
Pakhra
Seym
Desna
Sozh
Vyatka
Chepetsa
Cheptsa
Sura
Kuybyshev Reservoir
Saratov Reservoir
Saratov
Simbirsk
Samara Reservoir
Tolyatti
SAMARA BEND
Samara
Syzran
Syzran Reservoir
Volga Hills
Volgograd Reservoir
Volgograd
Balakovo
Orenburg
Buzuluk
Buzuluk Bor
Samara
Sok
Kinel
Bolshaya Kinel
Bolshoy Irgiz
Irgiz
Ilek
Or
Orsk
TURGAY PLATEAU
Oral
Saratov
Liski
Voronezh
Lebedyan
Dankov
Lipetsk
Tambov
Khlevnoye
Kursk
Tula
Novomoskovsk
Saransk
Mokshan
Tsna
Pitsa
Moksha
Vorona
Don
Sosna
Voronezh Reservoir
Voronezh
Tsimlyansk Reservoir
Volga-Don Ship Canal
Volgograd Dam
Kalach-na-Donu
Volgograd
Kamyshin
Ilovlya
Medveditsa
Khoper

through the Ukrainian crystalline massif and flows for 56 miles in a narrow, almost unterraced valley bounded by high, rocky banks. The Dnieper Rapids, which for centuries prevented continuous navigation, were once located there. The rapids were flooded by the backwaters of the Dnieper hydroelectric power station dam, above Zaporizhzhya, which raised the level of the river by 130 feet, backed its waters up to Dnipropetrovsk, and formed the Dnieper Reservoir.

Below Zaporizhzhya the Dnieper again passes into a wide valley with a high right bank (130 feet near Nikopol, 260 feet near Kherson). The slopes of the river there are very slight. Before the development of the Kakhovka Reservoir, the waters of which inundated a vast territory, the Dnieper split into numerous streams; flat swampy islands, overgrown with floodplain vegetation and reeds, lay among the channels. Today much of this is hidden under the waters of the reservoir. Below Kherson the Dnieper forms a delta, the many streams of which flow into the Dnieper estuary. Some have been deepened for navigational purposes.

Hydrology. The flow characteristics of the Dnieper have been thoroughly studied. Data on the river's annual runoff date to 1818, while estimates of the maximum discharges—computed from the old high-water marks—extend back more than 250 years. Hundreds of hydrometric stations and posts operate in the Dnieper basin. Under natural conditions the Dnieper had high flows during the spring and fall and low flows during the summer and winter; but dams have altered this regime, so that the river now has pronounced high flows in spring, diminishing flows in summer, and low flows from September to March. Spring snowmelt in the river's upper basin provides the majority of the annual discharge. About 60 percent of the annual runoff occurs from March to May. The period of stable ice on open water begins in the upper Dnieper at the beginning of December and in the lower Dnieper at the end of December. Thaw starts at the beginning of April in the upper course and in early March in the lower course.

Average flow

The average annual flow of the river at its mouth is some 59,000 cubic feet (about 1,670 cubic metres) per second; for individual years, the variations in runoff can be considerable. The water of the Dnieper is low in minerals and is soft. In a year the river carries an average of 8.6 million tons of dissolved matter to the sea.

Climate. The climate of the Dnieper basin is, on the whole, temperate and much milder and damper than that of regions to the east in southwestern Russia located at the same latitude. The continental nature of the climate increases from northwest to southeast. The mean annual air temperature is 41° F (5° C) in the upper part of the basin, 45° F (7° C) in the middle (near Kiev), and 50° F (10° C) in the lower reaches of the Dnieper. Winters in the northeast of the basin are long and persistent, whereas in the south they are shorter and milder with frequent thaws; in the north the mean temperature in January is 16° F (−9° C) and in the south 27° F (−3° C). The amount of precipitation decreases from north to south. On the slopes of the Valdai Hills and the Minsk Upland, annual precipitation is about 30–32 inches (760–810 millimetres), while in the lower Dnieper region it is about 18 inches. The mean annual precipitation for the upper Dnieper basin (above Kiev) is about 28 inches. The precipitation average for the entire basin is about 27 inches, with about half falling as rain during the summer and fall.

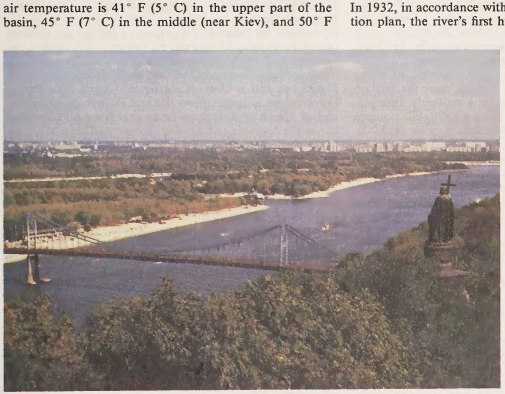
Plant and animal life. The Dnieper has diverse aquatic flora and fauna. In its upper course the plankton consist mainly of diatom and protococcal algae, rotifers, and *Bosmina.* Blue-green algae come from the mouth of the Pripet. In its lower course the amount of plankton decreases sharply under the influence of the reservoirs. More than 60 species of fish live in the Dnieper. Commercially important species include pike, roach, chub, ide, rudd, rapfen, tench, barbel, alburnum, golden shiner, goldfish, carp, catfish, burbot, pike perch, perch, and ruff. In the spring the lower Dnieper serves as a habitat for migratory and semimigratory fish (sturgeon, herring, roach, and others). The reservoirs have been stocked artificially with fish of commercial importance, including whitefish, pike perch, golden shiner, and carp.

History and economy. The Dnieper basin has been populated since ancient times. It was of central importance in the history of the peoples of eastern Europe, particularly in the founding of the ancient Kievan state. Along this waterway a system of river routes developed in the 4th to 6th century AD as a "route from the Varangians to the Greeks," connecting the Black Sea with the Baltic and linking the Slavs with both the Mediterranean and the Baltic peoples. Half of the Dnieper (about 700 miles) borders or passes through Ukrainian territory, and the river is for the Ukrainians the same kind of national symbol that the Volga River is for the Russians.

The first historical information about the Dnieper is recorded by the Greek historian Herodotus (5th century BC); the river is also mentioned later by the ancient writers Strabo and Pliny the Younger. It was first depicted on a map drawn by Ptolemy in the 2nd century AD. Instrument surveys of the Dnieper were begun early in the 18th century.

River development

Under the Soviets much work was undertaken for the multipurpose exploitation of the Dnieper's water resources. In 1932, in accordance with the Soviet Union's electrification plan, the river's first hydroelectric power station was



The Dnieper River at Kiev, Ukraine.
J. Allen Cash Photolibrary

completed at Zaporizhzhya in the region of the rapids. It was the largest power station in Europe until the construction of the huge power stations on the Volga in the 1950s. Completely destroyed by the German army during World War II, the dam was rebuilt in 1947, and its capacity increased. Hydroelectric power stations and reservoirs have also been built on the Dnieper at Kiev (completed 1966), Kaniv (1973), Kremenchuk (1961), Dniprodzerzhinsk (1965), and Kakhovka (1958). As a result of their construction, many problems have been solved: a continuous deepwater route from the mouth of the Pripet to the Black Sea has been created; the chronic water shortages in the Donets Basin and Kryvyy Rih industrial regions have been solved; and irrigation of arid lands in southern Ukraine and the Crimea has been made possible.

Regular navigation on the Dnieper extends as far upstream as Orsha, and, when the water is high, to Dorogobuzh. On the upper Dnieper the required depths are maintained by straightening and by dredging. Below the confluence with the Pripet, navigable locks make the passage of modern vessels possible. The principal cargoes are coal, ore, mineral building materials, lumber, and grain. The chief ports are Smolensk, Orsha, Mahilyow, Rechytsa, Loyew, Kiev, Cherkasy, Kremenchuk, Dnipropetrovsk, Zaporizhzhya, Nikopol, Kakhovka, and Kherson.

The Kryvyy Rih region is supplied with water from the Kakhovka Reservoir by means of the Dnieper–Kryvyy Rih Canal. The North Crimea Canal, which was completed in 1971, originates in the reservoir; the canal, 250 miles long, is designed for irrigation of the steppes of the Black Sea Lowland and the northern Crimea and for the creation of a water route from the Dnieper to the Sea of Azov.

Damming the Dnieper and diverting its waters, however, have radically altered its natural hydrology and ecology. Seasonal flow variations have been reduced, upstream access for anadromous fish has been reduced, effluents from cities and industry (as well as from increased agricultural runoff) have caused pollution, and diversion of water for irrigation and evaporation from reservoirs have lowered the annual outflow of the river by some 20 percent. In addition, the wetlands around the river's estuary have been seriously damaged by pollution and reduced discharge.

(A.P.D./P.P.M.)

DON RIVER

One of the great rivers of the European portion of Russia, the Don has been a vital artery in Russian history since the days of Peter I the Great, who initiated a hydrographic survey of its course. Throughout the world the river is associated with images of the turbulent and colourful Don Cossacks—romanticized in a famous series of novels by the 20th-century Russian writer Mikhail Sholokhov—and with a series of large-scale engineering projects that have enhanced the waterway's economic importance.

Source of the river

The Don River rises in the small reservoir of Shat, located in the Central Russian Upland near the city of Novomoskovsk. It flows generally in a southerly direction for a total distance of 1,162 miles (1,870 kilometres), draining a basin of some 163,000 square miles (422,000 square kilometres), before it enters the Gulf of Taganrog in the Sea of Azov. It is one of the major rivers of the European portion of Russia, lying between the Volga River to the east and the Dnieper River to the west. In its middle and lower courses, from the confluence with the Chornaya Kalitva River to its mouth, the Don forms an enormous eastward-bulging arc as far as its junction with the Ilovlya River. Near the top of the arc, the vast Tsimlyansk Reservoir begins. The Volga–Don Ship Canal stretches from the upper part of the reservoir to the Volga, which at that point is a mere 50 miles distant.

From its source in the Tula oblast, the Don crosses through the forest steppe and renowned steppe zones of southwestern Russia. Along the way it collects the waters of numerous tributaries, the most important of which are the Krasivaya Mecha, Sosna, Chornaya Kalitva, Chir, and Donets (right bank) and the Voronezh, Khopyor, Medveditsa, Ilovlya, Sal, and Manych (left bank). The river winds throughout its course, and the drop along its length is about 620 feet (190 metres).

Physical features. *Physiography.* In the upper portion of the Don—that is, as far downstream as the southeastward bend—the river flows along the eastern edge of the Central Russian Upland through a generally narrow valley. The right bank is pronounced, reaching heights of 160 feet above the river at the cities of Dankov and Lebedyan, and its limestone and chalk rocks are cut into by ravines and gullies. The left bank borders a flatter floodplain, and the river itself widens intermittently into small lakes; depths range from a few feet in the shoals to 33 feet, with a maximum width of 1,300 feet.

In the middle course, to the beginning of the Tsimlyansk Reservoir, the valley widens to about four miles, and its path is marked by floodplains, more small lakes, and relict channels; the banks, especially the right bank, become steeper, with chalk, limestone, and sandstone predominating. The river narrows to 330–1,300 feet.

The lower course is dominated by the nearly 190 miles of the Tsimlyansk Reservoir, completed in 1953. With an area of some 1,050 square miles and a maximum width of nearly 25 miles, the reservoir has an average depth of about 30 feet. Finally, the lower section of the Don has a valley width of 12–19 miles, with a huge floodplain and a braided river channel as much as 66 feet deep.

The landscape of the upper and middle Don basin is characterized on the right bank by undulating plains cut into by jagged gorges and on the left bank by the smoother, pond-dotted topography of the Oka-Don Lowland. Farther downriver the vast open landscapes of the steppes predominate. Rich black chernozem soils fill almost the entire basin, though there are patches of gray forest soil in the north, where forests cover up to 12 percent of the area.

Fluctuating water levels

Hydrology. The long-term fluctuations in the water level of the Don reach about 40 feet in the upper course, 25 feet in the middle course, and 20 feet in the lower course. The highest levels are in the spring, the lowest in autumn and winter. At the mouth of the Don, strong winds from the sea cause increases in the water level (wind surges). The average rate of discharge at the mouth of the Don is about 31,800 cubic feet (900 cubic metres) per second, but the river experiences great variation in its flow during the year. For example, at the city of Liski (formerly Georgiu-Dezh), in the river's upper course, the average flow is about 8,900 cubic feet per second, but flows range from 1,500 to approximately 395,000 cubic feet per second. There are corresponding variations as the annual flow increases downstream. At the city of Kalach-na-Donu about 65 percent of the annual flow occurs during April and May, compared with about 7 percent in March before the snowmelt begins. Below the Tsimlyansk Reservoir the flow has been partially regulated. At Nikolayevskaya, for example, 34 percent of the annual volume occurs in spring, 33 percent in summer, 22 percent in autumn, and 11 percent in winter.

The northern portion of the Don begins to freeze by mid-November and is clear of ice by mid-April. The Don's lower course is frozen from the end of November to the end of March at Kalach-na-Donu and from mid-December to the beginning of April at Rostov-na-Donu.

Climate. The climate of the basin is moderately continental, with average January temperatures ranging from 12° F to 18° F (−11° C to −8° C), while July readings reach 66° F to 72° F (19° C to 22° C). Annual precipitation diminishes from 23 inches (584 millimetres) in the north to 14–15 inches in the south.

History and economy. Archaeological evidence of early settlement of the Don River basin dates from the Upper Paleolithic (40,000–13,000 years ago). At the beginning of the 2nd century BC, tribes of herdsmen occupied the valley of the Don and developed livestock raising and crop agriculture there. The Tatars conquered the region during the first half of the 13th century AD. The Russian state, expanding southward from the Grand Principality of Moscow, incorporated the Don River basin between the middle of the 15th and 16th centuries. The famed Don Cossacks established themselves in independent military settlements along the middle and lower Don by the 16th century but subsequently came under tsarist control.

Since the early 1950s the Don has undergone intensive



Quays along the Don River at Rostov-na-Donu, Russia.
M. Koene—H. Armstrong Roberts

Construction of reservoirs

economic development. The key to this was the creation of the huge Tsimlyansk Reservoir along its lower course. The project included a hydroelectric station, a fish elevator, two navigation locks, an irrigation canal, a 1,580-foot concrete dam, and an eight-mile earthen dam. By 1975 an additional 116 reservoirs, with volumes exceeding 35 million cubic feet each, existed in the basin.

The Tsimlyansk Reservoir contributed to a rapid expansion of irrigation in the Don River basin, which grew from about 124,000 acres (50,000 hectares) in 1950 to nearly 2.5 million acres by 1980. In the upper basin an extensive network of ponds aids irrigation; these ponds are also used for raising fish.

The significance of the Don as a navigable waterway greatly increased with the construction of the Volga–Don Ship Canal. The river itself is navigable from the mouth to the city of Liski (a distance of 842 miles) and in the spring for another 150 miles upstream. Navigation in the lower course has been facilitated greatly by the Tsimlyansk project. Navigation at the mouth of the Don is occasionally hindered by the declines in water level induced by strong, persistent offshore winds, while dredging operations are necessary to maintain and improve navigation in the upper reaches. The largest ports are Kalach-na-Donu, Tsimlyansk, and Rostov-na-Donu.

The development of the Don has provided substantial economic benefits to the riverine populations as well as to the nation, but these alterations have reduced substantially the amount of water discharged at the river's mouth. This decrease—estimated in 1975 to be 20 percent of the 1950 level and still rising—has come chiefly from water diversion for irrigation and through evaporation from the artificial reservoirs; and, as a result of it, the salinity of the Sea of Azov has risen considerably, diminishing the sea's biological productivity and lowering fish catches.

(A.M.Ga./P.P.M.)

VOLGA RIVER

The significance of the river

Europe's longest river, the Volga (ancient Ra, medieval Itil or Etil), is the historic cradle of the Russian state. Its basin, sprawling across about two-fifths of the European part of Russia, contains almost half of the entire population of the Russian Republic. The Volga's immense economic, cultural, and historic importance—along with the sheer size of the river and its basin—ranks it among the world's great rivers. Rising in the Valdai Hills northwest of Moscow, the Volga discharges into the Caspian Sea, some 2,193 miles (3,530 kilometres) to the south. It drops slowly and majestically from its source 748 feet (228 metres) above sea level to its mouth 92 feet below sea level. In the process the Volga receives the water of some 200 tributaries, the majority of which join the river on its left bank. Its river system, comprising 151,000 rivers and permanent and intermittent streams, has a total length of about 357,000 miles.

Physical features. The river basin drains some 533,000 square miles (1,380,000 square kilometres), stretching from the Valdai Hills and Central Russian Upland in the west to the Ural Mountains in the east and narrowing sharply at Saratov in the south. From Kamyshin the river flows to its mouth uninterrupted by tributaries for some 400 miles. Four geographic zones lie within the Volga basin: the dense, marshy forest, which extends from the river's upper reaches to Nizhny Novgorod (formerly Gorky) and Kazan; the forest steppe extending from there to Samara (formerly Kuybyshev) and Saratov; the steppe from there to Volgograd; and semidesert lowlands southeast to the Caspian Sea.

Physiography. The course of the Volga is divided into three parts: the upper Volga (from its source to the confluence of the Oka), the middle Volga (from the confluence of the Oka to that of the Kama), and the lower Volga (from the confluence of the Kama to the mouth of the Volga itself). The Volga is a small stream in its upper course through the Valdai Hills, becoming a true river only after the entrance of several of its tributaries. It then passes through a chain of small lakes, receives the waters of the Selizharovka River, and then flows southeast through a terraced trench. Past the town of Rzhev, the Volga turns northeastward, is swelled by the inflow of the Vazuza and Tvertsa rivers at Tver (formerly Kalinin), and then continues to flow northeastward through the Rybinsk Reservoir, into which other rivers, such as the Mologa and the Sheksna, flow. From the reservoir the river proceeds southeastward through a narrow, tree-lined valley between the Uglich Highlands to the south and the Danilov Upland and the Galich-Chukhlom Lowland to the north, continuing its course along the Unzha and the Balakhna lowlands to Nizhny Novgorod. (Within this stretch the Kostroma, Unzha, and Oka rivers enter the Volga.) On its east-southeastward course from the confluence of the Oka to Kazan, the Volga doubles in size, receiving waters from the Sura and Sviyaga on its right bank and the Kerzhenets and Vetluga on its left. At Kazan the river turns south into the reservoir at Samara, where it is joined from the left by its major tributary, the Kama. From this point the Volga becomes a mighty river, which, save for a sharp loop at the Samara Bend, flows southwestward along the foot of the Volga Hills in the direction of Volgograd. (Between the Samara Bend and Volgograd it receives only the relatively small left-bank tributaries of the Samara, Bolshoy Irgiz, and Yeruslan.) Above Volgograd the Volga's main distributary, the Akhtuba, branches southeastward to the Caspian Sea, running parallel to the main course

of the river, which also turns southeast. A floodplain, characterized by numerous interconnecting channels and old cutoff courses and loops, lies between the Volga and the Akhtuba. Above Astrakhan a second distributary, the Buzan, marks the beginning of the Volga delta, which, with an area of more than 7,330 square miles, is the largest in Russia. Other main branches of the Volga delta are the Bakhtemir, Kamyzyak, Staraya (Old) Volga, and Bolda.

Hydrology. The Volga is fed by snow (which accounts for 60 percent of its annual discharge), underground water (30 percent), and rainwater (10 percent). The natural, untamed regime of the river was characterized by high spring floods (*polovodye*). Before it was regulated by reservoirs, annual fluctuations in level ranged from 23 to 36 feet on the upper Volga, from 39 to 46 feet on the middle Volga, and from 10 to 49 feet on the lower Volga. At Tver the average annual rate of river flow is about 6,400 cubic feet (180 cubic metres) per second, at Yaroslavl 39,000 cubic feet per second, at Samara 272,500 cubic feet per second, and at the river's mouth 284,500 cubic feet per second. Below Volgograd the river loses about 2 percent of its waters in evaporation. More than 90 percent of annual runoff occurs above the confluence of the Kama.

Former fluctuations in water level

Climate. The climate of the Volga basin changes significantly from north to south. From its source to the Kama confluence, it lies within a temperate climatic zone characterized by a cold, snowy winter and a warm, rather humid summer. From the Kama to below the Volga Hills, hot, dry summers and cold winters with little snow prevail. Toward the south and east, temperatures increase and precipitation decreases. The average January temperatures in the river's upper reaches range from 19° F (−7° C) to 6° F (−14° C) and those of July from 62° F (17° C) to 68° F (20° C), while on its lower reaches at Astrakhan corresponding temperatures are 19° F (−7° C) and 77° F (25° C). Annual rainfall ranges from 25 inches (635 millimetres) on the northwest to 12 inches on the southeast. Evaporation of precipitation ranges from 20 inches in the northwest to eight inches in the southeast. The upper and middle courses of the Volga begin to freeze at the end of November, the lower reaches in December. The ice breaks up at Astrakhan in mid-March, at Kamyshin at the beginning of April, and everywhere else in mid-April. The Volga is generally free of ice for about 200 days each year and for about 260 days near Astrakhan. As great masses of water accumulated within the reservoirs constructed during the Soviet period, however, the temperature regime of the Volga was so changed that the duration of ice increased on the headwaters of the reservoirs and decreased on the stretches below the dams.

The changing river regime

The economy. *Dams and reservoirs.* A string of huge dams and reservoirs now line the Volga and its major tributary, the Kama River, converting them from free-flowing rivers to chains of man-made lakes. All the reservoir complexes include hydroelectric power stations and navigation locks. The uppermost complex on the Volga, the Ivankovo , with a reservoir covering 126 square miles, was completed in 1937, and the next complex, at Uglich (96 square miles), was put into operation in 1939. The Rybinsk Reservoir, completed in 1941 and encompassing an area of about 1,750 square miles, was the first of the large reservoir projects. Following World War II, work continued below Rybinsk. The reservoirs at Nizhny Novgorod and Samara were both completed in 1957, and the Cheboksary Reservoir, located between them, became operational in 1980. The huge reservoir at Samara, with an area of some 2,300 square miles, is the largest of the Volga reservoir system; it not only impounds the waters of the Volga but also backs water up the Kama for some 375 miles. The Saratov and Volgograd reservoirs (completed in 1968 and 1962, respectively) are the last such bodies on the Volga itself. The chain on the Kama consists of three reservoirs, the newest of which—the Lower Kama Reservoir—became operational in 1979. There are a total of eight hydroelectric stations on the Volga and three on the Kama, which combined have an installed generating capacity of some 11 million kilowatts of power.

Navigation. The Volga, navigable for some 2,000 miles, and its more than 70 navigable tributaries carry more than half of all Soviet inland freight and nearly half of all the passengers who use Soviet inland waterways. Construction materials and raw materials account for about 80 percent of the total freight; other cargoes include petroleum and petroleum products, coal, foodstuffs, salt, tractors and agricultural machinery, automobiles, chemical apparatus, and fertilizers. The major ports on the Volga are Tver, Rybinsk, Yaroslavl, Nizhny Novgorod, Kazan, Simbirsk (formerly Ulyanovsk), Samara, Saratov, Kamyshin, Volgograd, and Astrakhan.

Freight patterns

The Volga is joined to the Baltic Sea by the Volga–Baltic Waterway, which, in turn, is joined to the White Sea (via Lake Onega) by the White Sea–Baltic Canal; to the Moscow River, and hence to Moscow, by the Moscow Canal; and to the Sea of Azov by the Volga–Don Ship Canal. The river has thus become integrated with virtually the entire waterway system of eastern Europe.

Environmental changes. Although the extensive development of the Volga has made a major contribution to the Soviet economy, it also has had adverse ecological consequences. The system of dams and reservoirs has blocked or severely curtailed access for such anadromous species as the beluga sturgeon (famous for the caviar made from its roe) and whitefish (*belorybitsa*), which live in the Caspian Sea but spawn in the Volga and other inflowing rivers, and it has fundamentally altered the habitat of the nearly 70 species of fish native to the river. These changes—along with pollution by industrial and municipal effluents and by agricultural runoff—have led to deterioration of the major Volga fisheries. Water loss by impoundment and evaporation and by diversion (chiefly for irrigation) have diminished discharge at the mouth of the Volga compared with natural conditions, and this has contributed to an almost steady decline in the level of the Caspian Sea since 1930. Intensive efforts to alleviate these man-made influences, however, have been under way for a number of years. For example, some three-fifths of the Caspian sturgeon are now bred artificially rather than in their natural spawning grounds.

Study and exploration. The Volga was known to the Alexandrian geographer Ptolemy (2nd century AD), to the Slavs, and to the Arab geographers of the 10th and 11th centuries. Information on it is contained in the *Kniga*

Jonathan Wright—Bruce Coleman Inc.



Fishing for beluga sturgeon in the Volga River, Volgograd, Russia.

bolshomu chertyozhu (1627; "Book of the Great Chart") and in a hydrographic description of 1636. Its flow was first measured below Kamyshin by the Englishman John Perry in 1700. Two pioneer Russian navigators, Makeyev and Gavril Andreyevich Sarychev, surveyed the stretch between Tver and Nizhny Novgorod in 1782–83; in 1809–17 and 1829 the Maritime Bureau surveyed the delta and measured its depth; and from 1875 to 1894 the river was investigated from the Rybinsk to the Volga mouth. Investigations of the upper Volga were made from 1896 to 1901, and in 1894 the upper reaches of the Volga, Oka, Syzran, and other rivers were also examined. Many institutes carried out hydrographic and hydrometric research during and after the Soviet period; and more than 500 points have been established to monitor the water levels of the Volga. (P.S.K./P.P.M)

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European History and Culture

Europe is a more ambiguous term than most geographic expressions. Its etymology is doubtful, as is the physical extent of the area it designates. Its western frontiers seem clearly defined by its coastline, yet the position of the British Isles remains equivocal. To outsiders, they seem clearly part of Europe. To many British and some Irish people, however, "Europe" means essentially continental Europe. To the south, Europe ends on the northern shores of the Mediterranean Sea. Yet, to the Roman Empire, this was *mare nostrum* ("our sea"), an inland sea rather than a frontier. Even now, some question whether Malta or Cyprus is a European island. The greatest uncertainty lies to the east, where natural frontiers are notoriously elusive. If the Ural Mountains mark the eastern boundary of Europe, where does it lie to the south of them? Can Astrakhan, for instance, be regarded as European? Can even the Crimea or the Ukraine? The questions have more than merely geographic significance.

These questions have acquired new importance as Europe has come to be more than a geographic expression. After World War II, much was heard of "the European idea." Essentially, this meant the idea of European unity, at first confined to western Europe but by the beginning of the 1990s seeming able at length to embrace central and eastern Europe as well.

Unity in Europe is an ancient ideal. In a sense it was implicitly prefigured by the Roman Empire. In the Middle Ages, it was imperfectly embodied first by Charlemagne's empire and then by the Holy Roman Empire and the Roman Catholic church. Later, a number of political theorists proposed plans for European union, and both Napoleon Bonaparte and Adolf Hitler tried to unite Europe by conquest.

It was not until after World War II, however, that European statesmen began to seek ways of uniting Europe peacefully on a basis of equality instead of domination by one or more great powers. Their motive was fourfold: to prevent further wars in Europe, in particular by reconciling France and Germany and helping to deter aggression by others; to eschew the protectionism and "beggar-my-neighbour" policies that had been practiced between the wars; to match the political and economic influence of the world's new superpowers, but on a civilian basis; and to begin to civilize international relations by introducing common rules and institutions that would identify and promote the shared interests of Europe rather than the national interests of its constituent states.

Underlying this policy is the conviction that Europeans have more in common than divides them, especially in the modern world. By comparison with other continents, western Europe is small and immensely varied, divided by rivers and mountains and cut into by inlets and creeks. It is also densely populated—a mosaic of different peoples with a multiplicity of languages. Very broadly and inadequately, its peoples can be sorted into Nordic, Alpine or Celtic, and Mediterranean types, and the bulk of their languages classified as either Romance or Germanic. In this sense, what Europeans chiefly share is their diversity; and it may be this that has made them so energetic and combative. Although uniquely favoured by fertile soils and temperate climates, they have long proved themselves warlike. Successive waves of invasion, mainly from the east, were followed by centuries of rivalry and conflict, both within Europe and overseas. Many of Europe's fields have been battlefields, and many of Europe's cities, it has been said, were built on bones.

Yet Europeans have also been in the forefront of intellectual, social, and economic endeavour. As navigators, explorers, and colonists, for a long time they dominated much of the rest of the world and left on it the impress of their values, their technology, their politics, and even their dress. They also exported both nationalism and weaponry.

Then, in the 20th century, Europe came close to destroying itself. World War I cost more than 8 million European lives, World War II more than 18 million in battle, bombing, and systematic Nazi genocide—to say nothing of the 30 million who perished elsewhere.

As well as the dead, the wars left lasting wounds, psychological and physical alike. But, whereas World War I exacerbated nationalism and ideological extremism in Europe, World War II had almost the opposite effect. The burned child fears fire; and Europe had been badly burned. Within five years of the war's end, the French foreign minister Robert Schuman, prompted by Jean Monnet, proposed to Germany the first practical move toward European unity, and the West German chancellor Konrad Adenauer agreed. Others involved in that first step included the statesmen Alcide De Gasperi and Paul-Henri Spaak. All except Monnet were men from Europe's linguistic and political frontiers—Schuman from Lorraine, Adenauer from the Rhineland, De Gasperi from northern Italy, Spaak from bilingual Belgium. Europe's diversity thus helped foster its impulse to unite. (R.J.Ma.)

This article treats the history of European society and culture. For a discussion of the physical and human geography of the continent, see EUROPE. For the histories of individual countries, see specific articles by name—*e.g.*, FRANCE, HUNGARY, and SPAIN. Articles treating specific topics in European history include BYZANTINE EMPIRE, THE HISTORY OF THE; STEPPE, THE HISTORY OF THE EURASIAN; and WORLD WARS. For the lives of prominent European figures, see specific biographies by name—*e.g.*, CHARLEMAGNE, ERASMUS, and BISMARCK. Related topics are discussed in such articles as those on religion (*e.g.*, EUROPEAN RELIGIONS, ANCIENT; CHRISTIANITY; and JUDAISM), literature (*e.g.*, ENGLISH LITERATURE, SCANDINAVIAN LITERATURE, and RUSSIAN LITERATURE), and the fine arts (*e.g.*, PAINTING, THE HISTORY OF WESTERN; and MUSIC, THE HISTORY OF WESTERN).

For coverage of related topics on the history of Europe in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 912, 921, 923, 961, 962, 963, 971, and 972, and the *Index*.

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Prehistory

The appearance of anatomically modern humans in Europe about 35,000 BC was accompanied by major changes in culture and technology. There was a further period of significant change after the last major Pleistocene glaciation, which included the widespread adoption of farming and the establishment of permanent settlements from the 7th millennium BC. These laid the foundation for all future developments of European civilization.

Uncovering the European past

Knowledge of these early periods of the European past is entirely dependent on archaeology. The evidence, which has almost all been collected since the middle of the 19th century, varies greatly from region to region and is limited by what was deposited and by whether what was deposited has survived. The archaeological evidence has also been disturbed by a range of human and natural processes, from glacial activity to farming and modern development. Modern techniques have greatly increased the amount of information available, but many parts of the story of the past may be difficult or impossible to recover, and the evidence that has been revealed needs to be assessed in the light of all these factors.

Dating depends on scientific methods. Cores through deep ocean-floor sediments and the Arctic ice cap have provided a continuous record of climatic conditions for the last one million years, but individual sites cannot easily be matched to it. Radiocarbon dating is effective to 35,000 years ago, and prior to that other scientific methods can be used with varying degrees of precision.

Tree rings give precise dates for wood as early as the 5th millennium BC. Detailed typological studies, especially of pottery and stone tools, can be used to establish the relative sequence of material. The dates cited in this section are based on various scientific methods. For the earliest period, to about 35,000 BC, they are derived from absolute determinations by potassium-argon and thorium-uranium dating, together with correlations to the deep-sea and ice-core sequences; for the later period, they are derived primarily from radiocarbon determinations, calibrated where appropriate to give actual calendar years.

PALEOLITHIC SETTLEMENT

Earliest developments. The period of human activity to the end of the last major Pleistocene glaciation, about 8300 BC, is termed the Paleolithic Period (Old Stone Age); that part of it from 35,000 to 8300 BC is termed the Upper Paleolithic.

Extreme changes in climate

The climatic record shows a cyclic pattern of warmer and colder periods; in the last 750,000 years, there have been eight major cycles, with many shorter episodes. In the colder periods, the Arctic and Alpine ice sheets expanded, and sea levels fell. Some parts of southern Europe may have been little affected by these changes, but the advance and retreat of the ice sheets and accompanying glacial environments had a significant impact on northern Europe; at their maximum advance, they covered most of Scandinavia, the North European Plain, and Russia. Human occupation fluctuated in response to these changing conditions, but continuous settlement north of the Alps required a solution to the problems of living in extremely cold conditions.

By 1,000,000 years ago hominids were widely distributed in Africa and Asia, and some finds in Europe may be that early. The earliest securely dated material is from Isernia la Pineta in southern Italy, where stone tools and animal bones were dated to about 730,000 BC. Thereafter the evidence becomes more plentiful, and by 375,000 BC most areas except Scandinavia, the Alps, and northern Eurasia had been colonized.

Fossil remains of the hominids themselves are rare, and most of the evidence consists of stone tools. The simplest were chopping tools made from pebbles with a few flakes struck off to create an edge. These were replaced by more complex traditions of toolmaking, which produced a range of hand axes and flake tools; these industries are referred to as Acheulian, after the French site of Saint-Acheul. Some of the tools were for woodworking, but only rarely do any tools of organic material, such as wooden spears, survive as evidence of other Paleolithic technologies.

Techniques for obtaining food

The subsistence economy depended on hunting and gathering. Population densities were necessarily low, and group territories were large. The main evidence is animal bones, which suggest a varied reliance on species such as rhinoceros, red deer, ibex, and horse, but it is difficult to reconstruct how such food was actually acquired. Open confrontation with large animals, such as the rhinoceros, is unlikely, and they were probably killed in vulnerable locations such as lake-edge watering spots; at La Cotte de Sainte Brelade in the Channel Islands, rhinoceroses and mammoths were driven over a cliff edge. Scavenging meat from already dead animals also may have been important. Food resources such as migratory herds and plants were available only seasonally, so an annual strategy for survival was necessary. It is not clear, however, how it was possible to store food acquired at times of plenty; carcasses of dead animals frozen in the snow would have provided a store of food.

From the beginning of the last major Pleistocene glaciation about 120,000 BC, the hominid fossils belong to the Neanderthals, who have been found throughout Europe and western Asia, including the glacial environments of central Europe. They were biologically and culturally adapted to survival in the harsh environments of the north, though they are also found in more moderate climates in southern Europe and Asia. Finds of stone tools from the Russian plains suggest the first certain evidence of colonization there by 80,000 BC. Despite their heavy skeletons and developed brow ridges, Neanderthals were probably little different from modern humans. Some of the skeletal remains appear to be from deliberate burials, the first evidence for such careful behaviour among humans.

Upper Paleolithic developments. From about 35,000 BC, anatomically modern humans—*Homo sapiens sapiens*, the ancestor of modern populations—were found throughout Europe, and the following period was marked by a series of important technological and cultural changes, in marked contrast to the comparative stability of the preceding hundreds of thousands of years. These changes cannot be simply explained as the result of the sudden appearance of modern, intelligent humans. The preceding Neanderthals differed little in brain size, and some Neanderthal remains are associated with tool assemblages of the new technology as well as with behavioral practices such as burial. The problem of the relationship of the Neanderthals to the sudden appearance of modern humans is difficult; possible explanations include total replacement of Neanderthals by modern populations, interbreeding with an immigrant modern population, or Neanderthals as ancestors of modern humans.

Appearance of specialized tools

The technological changes of the Upper Paleolithic Period include the disappearance of heavy tools such as hand axes and choppers and the introduction of a much wider range of tools for special purposes, many of them made from long, thin blades. Tools made of antler, bone, and ivory were also widely used, apparently for the first time. After 18,000 BC there were further innovations. Flint was pretreated by heating to alter its structure and make flaking easier, and new tool types included harpoons, needles for sewing fur garments, and small blades for hafting in spears and arrows. The new technologies and more complex and specialized tool types suggest a major change in the pattern of energy expenditure. Much more effort was devoted to the careful use of resources, and tools were prepared in advance and retained, rather than made and discarded expediently.

Sites of this period are found throughout Europe, though at the height of the last major Pleistocene glaciation (about 35,000 to 13,000 BC) much of the North European Plain was abandoned as populations moved south. There is a greatly increased number of sites, many of which show evidence of more permanent structures such as hearths, pavements, and shelters built of skins on a frame of bone or wood. Some of this increase may be due to the greater likelihood of finding sites of this more recent period, but it may also indicate a growing population density and a greater investment of energy in construction.

Subsistence still depended on hunting and gathering, but the role of plant foods is difficult to estimate. As population increased, group territories may have become smaller, and the increasingly harsh environments of the last glaciation necessitated appropriate strategies for survival. Some sites show a concentration on particular large animal species (horse and reindeer in the north and ibex and red deer in the south), but there is also evidence for the increasing use of other food resources, such as rabbits, fish, and shellfish. In comparison with large animals, these produced small amounts of food, but they were an important addition because of their greater reliability. Settlement patterns reflect these social and economic strategies, which allowed most of the population to stay at one location for long periods while others left to procure distant resources.

Some of the most important evidence is for change in social organization and human behaviour. There is increasing evidence for deliberate and careful burial, sometimes with elaborate treatment of the dead. At Sungir in Russia and at Grotta Paglicci in Italy, for instance, the dead were buried with tools and ornaments, indicating a respect for their identity or status. Personal ornaments, especially bracelets, beads, and pendants, are common finds. They were made from a wide variety of materials, including animal teeth, ivory, and shells; some appear to have been sewn onto garments. Such ornamentation not only shows an elaboration of clothing and an interest in display but may also have been used as a means of signaling individual or group identity.

The earliest art objects in Europe also date from this period. There are small figurines of animals and humans



Upper Paleolithic Venus figurine found at Willendorf, Lower Austria. Limestone, originally coloured with red ochre. In the Naturhistorisches Museum, Vienna.
Archiv für Kunst und Geschichte, Berlin

made from finely carved bone or ivory. Among the most striking are the so-called Venus figurines, stylized representations of females with large breasts and buttocks, which show a marked degree of similarity from France to Russia. There are also thousands of small stone plaques engraved with representations of humans and animals.

Art is also found in caves, particularly in France and Spain, in caves such as Lascaux and Altamira, though there is one cave at Kapova in the Urals with decoration in a similar style. In some cases, reliefs of humans or animals are carved on rock walls, but the most spectacular artworks are the paintings, dominated by large animals such as mammoth, horse, or bison; human figures are rare, but there are many other signs and symbols. The precise meaning of this art is impossible to recover, but it appears to have played a significant part in group ceremonial activity; much of it is in almost inaccessible depths of caves and may have been important for rituals of hunting or initiation.

The similarity in style over great distances—seen most clearly in the case of the Venus figurines—is evidence for the existence of extensive social networks throughout Europe. Material items also were transmitted over long distances, especially particular types of flint, fossil shell, and marine mollusks. Such networks were most extensive at the height of the last glaciation and were an important social solution to the problem of surviving in extreme climates; they provided alliances to supply food and other material resources as well as information about a far-flung environment. Human developments during this so-called Ice Age thus included not only technological, economic, and social solutions to the problems of adaptation and survival but also an increased awareness of individual and group identity and a new field of symbolic and artistic activity.

MESOLITHIC ADAPTATIONS

The extreme conditions of the last Pleistocene glaciation began to improve about 13,000 BC as temperatures slowly rose. The Scandinavian Ice Sheet itself started to retreat northward about 8300 BC, and the period between then and the origins of agriculture (at various times in the 7th to 4th millennia, depending on location) was one of great environmental and cultural change. It is termed the Mesolithic Period (Middle Stone Age) to emphasize its transitional importance, but the alternative term Epipaleolithic, used mostly in eastern Europe, stresses the continuity with processes begun earlier.

As the ice sheets retreated, vast areas of new land in northern Europe were opened up for human occupation. Resettlement began in some short warmer episodes at the end of the last glaciation. In the longer term, the melting of the Arctic glaciers produced a rise in sea levels, though this was to some extent offset by a rise in land levels as the weight of the overlying ice was removed. The combined effect of these processes was to flood large areas of land in the Mediterranean and especially in the North Sea basin. Britain was isolated from the continent during the 7th millennium, and the modern coastline was broadly established by the 4th.

The changes in physical landforms were accompanied by similarly major changes in the environment. The rising temperature and humidity led to the increased growth of plant life, including birch and pine as well as smaller trees and bushes that produced nuts and fruit. Continued climatic amelioration meant further environmental change, and the initial open forest progressively gave way to climax forest dominated by oak and elm, which crowded out many of the smaller species. There were similar changes among animals. The large animals of the Ice Age such as bison and mammoth disappeared, either because of climatic change or from overhunting, and reindeer herds moved northward in search of colder conditions. The European forests were dominated by smaller animals, such as wild cattle, pigs, and deer, with ibex in the south.

The evidence for human exploitation of these changing environments varies considerably, depending on the precise range of regionally available resources. As the reindeer moved north, so did some human groups. Others adapted to the new animal and plant resources available. Wild cattle, deer, and pigs were widely hunted, as well as many types of bird. Fish were also caught, including river species such as salmon and carp and many sea species. On the western coasts, shellfish also were exploited. The role of plant foods is difficult to estimate, but there is evidence for the use of many species, including hazelnuts and various berries.

These new patterns of economy needed new technologies. Stone tools increasingly took the form of small blades for tipping or hafting in arrows and spears. Where conditions allow their survival, it is possible to see many new tools and equipment made of organic materials, though some, such as the bow and arrow, may have been made in earlier periods. Hooks, nets, and traps for fishing; birch bark containers; and textiles made from plant fibres are all known. Canoes and paddles also have been found.

Management of economic resources

Though subsistence was dependent on hunting and gathering seasonally available resources, those resources could be managed in elementary ways. Hunting strategies concentrated on taking adult males, preserving the young and female animals needed to maintain the herds. Dogs were a source of meat and fur, but they may also have been used in hunting. It may have been possible to control the movement of herds by making clearances in the forest, thus attracting animals to the new growth; the evidence for fire and repeated small-scale clearances supports this theory. Plants may have been husbanded. In these ways, human control was exercised over the environment and its resources.

Human occupation expanded throughout Europe, and many areas show a pattern of settlement with base camps occupied by all members of the group for some part of the year and small sites used for the exploitation of some particular resource. Wide social networks continued to exist, as shown by the long-distance exchange of some raw materials such as special types of rock. Mobility may have been important for ensuring an adequate annual subsistence, but some environments, such as the coastal regions of the Baltic and the west, may have allowed the possibility of more permanent settlement. Reliance on fish and shellfish there might be thought a last resort; alternatively, it could have been a purposive choice of resources that

would allow permanent residence. Denmark and western France have traditions of deliberate human burial that support this theory.

Thus the environmental changes were met with a variety of social, economic, and technological responses, but human society did not adapt passively. Opportunities existed to manage the environment more actively and to make choices for social rather than purely survival purposes.

THE NEOLITHIC PERIOD

The adoption of farming. From about 7000 BC in Greece, farming economies were progressively adopted in Europe, though areas farther west, such as Britain, were not affected for two millennia and Scandinavia not until even later. The period from the beginning of agriculture to the widespread use of bronze about 2300 BC is called the Neolithic (New Stone Age).

Agriculture had developed at an earlier date in the Middle East, and the relationship of Europe to that area and the mechanism of the introduction of agriculture have been variously explained. At one extreme is a model of immigrant colonization from the Middle East, with the agricultural frontier pushing farther westward as population grew and new settlements were founded. A variation of this model denies the uniformity of such a "wave of advance" and stresses the possibility of a more irregular pioneering movement. At the other extreme is a model of agricultural adoption by indigenous Mesolithic groups, with a minimum of reliance on any introduced people or resources.

In favour of the intrusive model is the nature of the crops that formed the basis of early agriculture; the main cereals were emmer wheat, einkorn wheat, and barley, together with other plants such as peas and flax. These had all been domesticated in the Middle East, where their wild progenitors were found. The material culture of the earliest farmers in Greece and southeastern Europe also shows great similarity to that of the Middle East. On the other hand, the animals important to early agriculture are not so clearly introduced; wild sheep and goats may have been available in southern Europe, and cattle were probably domesticated in southeastern Europe at least as early as in the Middle East. There also were definite European contributions; the dog was domesticated in Europe in the Mesolithic Period, and evidence suggests that the horse was first domesticated on the Western Steppe.

Domestication of the dog and horse

The process of agricultural adoption, furthermore, was neither fast nor uniform. It took at least 4,000 years for farming to reach its northern limit in Scandinavia, and there it was the success of fishing and sealing that allowed agriculture as a desirable addition to the economy. In many areas of western Europe, it is likely that domesticated animals were used before the adoption of agricultural plants. It is also possible to argue for a considerable Mesolithic contribution, especially in the north and west. Not only did some areas continue to rely on hunting and gathering in addition to farming but there was also continuity of settlement location and resource use, especially of stone for tools. Despite the disappearance of the small blades previously used for spears and arrows and the appearance of heavy tools for forest clearance, there was some continuity of tool technology.

The adoption of farming is unlikely to have been a simple or uniform process throughout Europe. In some regions, especially Greece, the Balkans, southern Italy, central Europe, and Ukraine, actual colonization by new populations may have been important; elsewhere, especially in the west and north, a gradual process of adaptation by indigenous communities is more likely, though everywhere the pattern would have been mixed.

The consequences of the adoption of farming were important for all later developments. Permanent settlement, population growth, and exploitation of smaller territories all brought about new relationships between people and the environment. Mobility had previously necessitated small populations at low densities and had allowed only material items that could be carried, with little investment in structures; these restraints were removed, and the opportunity was created for many new crafts and technologies.

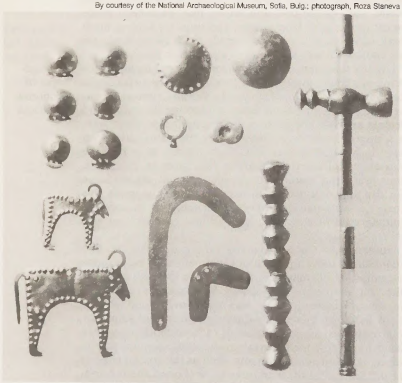
Early farming communities

The earliest evidence for agriculture comes from sites in Greece, such as Knossos and Argissa, soon after 7000 BC. During the 7th millennium, farming was widespread in southeastern Europe. The material culture of this region bears a strong similarity to that of the Middle East. Pottery making was introduced, and a variety of highly decorated vessels was produced. Permanent settlements of small mud-brick houses were established; continuous rebuilding of such villages on the same spot produced large settlement mounds, or tells. Clay figurines, mostly female, are common finds in many houses, and there may also have been special shrines or temples. The precise beliefs cannot be ascertained, but they suggest the importance of ritual and religion in these societies. By the 5th and 4th millennia, some of these sites, such as Sesklo and Dhimini in Greece, were defended. From the early 5th millennium, there is evidence for the development of copper and gold metallurgy, independently of Middle Eastern traditions, and copper mines have been found in the Balkan Peninsula. Metal products included personal ornaments as well as some functional items; the cemetery at Varna, Bulg., contained many gold objects, with large collections in some graves. Control of ritual, technology, and agriculture, as well as the need for defense, all suggest the growing differentiation within Neolithic society.

In the central and western Mediterranean, the clearest evidence is from southern Italy, where a mixed farming economy was established in the 7th millennium. Many large villages, often surrounded by enclosure ditches, have been recognized. Elsewhere in the region, domesticated crops and animals were adopted more slowly into the indigenous economies. New technologies also were adopted; pottery decorated with characteristic impressed patterns was made, and by the 4th millennium copper was being worked in Spain. The major islands of the Mediterranean were colonized. The general picture is one of small-scale regional development. One such regional pattern was on Malta, where a series of massive stone temples was constructed from the early 4th millennium.

In a band across central and western Europe, the earliest farmers from 5400 BC onward are represented by a homogeneous pattern of settlements and material culture, named the LBK Culture (from *Linienbandkeramik* or *Linearbandkeramik*), after the typical pottery decorated with linear bands of ornament. The same styles of pottery and other material are found throughout the region, and their settlements show a regular preference for the easily worked and well-drained loess soils. The houses were

By courtesy of the National Archaeological Museum, Sofia, Bulg.; photograph, Roza Stanева



Neolithic decorative gold objects from a grave in the cemetery at Varna, Bulg. In the National Archaeological Museum, Sofia, Bulg.

20 to 23 feet (6 to 7 metres) wide and up to 150 feet long and possibly included stalling for animals; in some areas they were grouped in large villages, but elsewhere there was a dispersed pattern of small clusters of houses. Some cemeteries are known; they show a concentration of objects deposited with older males. About 4700 BC the cultural homogeneity ended, and regional patterns of settlement and culture appeared as the population grew and new areas were exploited for farming. Some of the best information comes from villages on the edges of lakes in France and Switzerland, where organic material has been preserved in damp conditions.

Farming also spread northeastward into the steppe north of the Black Sea. Before 6000 BC domesticated animals and pottery were found there, but in societies that still relied heavily on hunting and fishing. By about 4500 BC a new pattern of villages, such as at Cucuteni and Tripolye, was established with a mixed farming economy. Some of these villages contained many hundreds of houses in a planned layout, and they were increasingly surrounded by massive fortifications. Farther east across the steppe as far as the southern Urals, pottery, domesticated animals, and cereals were progressively added to an indigenous hunting-and-gathering economy, and the horse was domesticated. Nomadic pastoral economies developed by the 2nd millennium.

Spread of farming to northern and western Europe

Farming extended from central to northern Europe only after a long interval. For a millennium, agriculturalists and hunter-gatherers were in contact and pottery was adopted or exchanged, but domesticated animals and crops were only introduced into northern Germany, Poland, and southern Scandinavia about 4200 BC, apparently after a decline in the availability of marine food resources. Farming was rapidly adopted as the mainstay of subsistence and expanded to its maximum climatic viability in Scandinavia. By the middle of the 4th millennium, large communal tombs were being built, frequently of megalithic (large-stone) construction.

In western Europe, there was a similar delay in the spread of farming. In western France, domesticated animals were added to hunting and gathering in a predominantly stock-based economy, and pottery was also adopted. In Britain and Ireland, forest clearance as early as 4700 BC may represent the beginnings of agriculture, but there is little evidence for settlements or monuments before 4000 BC, and hunting-and-gathering economies survived in places. The construction of large communal tombs and defended enclosures from 4000 BC may mark the growth of agricultural populations and the beginning of competition for resources. Some of the enclosures were attacked and burned, clear evidence of violent warfare. The tombs, of earth and timber or of megalithic construction, contained communal burials and served as markers for claims to farming territories as well as foci for the worship of ancestors. Some, such as the tombs of Brittany and Ireland, contained elaborately decorated stones.

The late Neolithic Period. *Agricultural intensification.* From the late 4th millennium a number of developments in the agricultural economy became prominent. They did not, however, begin all at once nor were they found everywhere. Some of them may have been in use for some time, and there also are distinct regional variations. Cumulatively, however, they add up to a new phase of agricultural organization.

One of the most important developments was the management of animal herds for purposes other than the provision of meat. In the case of cattle, there is some evidence for milk production earlier, but dairying appears to have taken on a much more significant role from this time. Oxen were raised to provide traction. Sheep were managed not for meat but primarily as a source of manure and wool. Textiles in the early Neolithic Period were predominantly made of flax, but from the early 3rd millennium wool was widely used, and spinning and weaving became important crafts and new ways of exploiting agricultural resources. New crops also were introduced. The most important were the vine and the olive, found in Greece from the early 3rd millennium. These tree crops represented an important addition to the range of agricultural produce and formed the basis for later developments in the Aegean.

Plows and wheeled vehicles

There were also new technologies, especially the use of animal traction for the plow and for wheeled vehicles. The earliest evidence for plowing consists of marks preserved in the soil under burial mounds and dated to the end of the 4th millennium. A clay model of a wheeled cart of the same date is known from a grave at Szigetszentmárton, Hung., and actual wheels from northern Europe by 2500 BC. In southeastern Spain, the most arid area of Europe, irrigation systems were probably introduced. These all represent important new technologies applied to agriculture and an intensification of energy expenditure in that field.

The innovations outlined above marked the development of early agriculture toward a system more specifically adapted to the European environment and capable of producing a much wider range of outputs, especially of nonfood products. Some, such as wine and cloth, had a particular social significance, and others, especially the wheeled vehicle, led to further developments. The new agricultural regime also showed a better adaptation to the wide variety of regional environments in Europe and permitted expansion into new ecological zones. Whereas the earliest farmers mostly preferred the prime arable soils, such as the loess of central Europe, it was now possible, especially with the use of sheep, to exploit many less fertile soils.

© Hungarian National Museum, Budapest: photograph, Kardos Judit



Clay model of a wheeled cart from a grave at Szigetszentmárton, Hung., end of the 4th millennium BC. In the Hungarian National Museum, Budapest, Hung.

Social change. The period from the late 4th millennium also saw many important social changes. They varied from region to region but laid the foundations for the society of the Bronze Age, which followed.

In southeastern Europe about 3200 BC, there was a major break in material culture and settlement patterns. The old styles of decorated pottery were replaced with new plainer forms, and the evidence for ritual, such as the figurines, ends. Many of the long-occupied tell sites were abandoned; the new settlement pattern shows many smaller sites and some larger ones which may have played a central role. In Greece there were similar changes, with population expansion especially in the south and the emergence of some sites as centres of authority; this period marked the beginning of the Aegean Bronze Age.

Elsewhere in the Mediterranean the changes are most marked in parts of Iberia. At Los Millares in southeastern Spain and in southern Portugal at sites such as Vila Nova de São Pedro, strongly fortified settlements accompanied by cemeteries containing rich collections of prestige goods suggest the appearance of a more hierarchically organized society. Similar trends toward the emergence of sites of central authority took place in southern France, but there is little sign of such developments in Italy.

In central and northern Europe, changes of a different

New burial rites

nature began about 2800 BC. The most obvious feature is two phases of new burial rites, comprising individual rather than communal burials with a particular emphasis on the deposition of prestige grave goods with adult males. The first phase, characterized by Corded Ware pottery and stone battle-axes, is found particularly in central and northern Europe. The second phase, dated to 2500–2200 BC, is marked by Bell Beaker pottery and the frequent occurrence of copper daggers in the graves; it is found from Hungary to Britain and as far south as Italy, Spain, and North Africa. At the same time, there was an increase in the exchange of prestige goods such as amber, copper, and tools from particular rock sources.

Both of these burial rites have been attributed to invading population groups. On the other hand, they may also be seen as a new expression of an ideology of social status, emphasizing control of resources rather than ancestral descent. Such an explanation fits better with a picture of slow internal development within European society. The new ideology did not prevail everywhere, however, and in Britain, for instance, the 3rd millennium saw the construction of massive ceremonial monuments such as Avebury and Stonehenge, before the introduction of individual burial rites at the end of the millennium.

The Indo-Europeans. When there is evidence for the languages spoken in Europe at the end of the prehistoric period, it is clear that with few exceptions, such as Basque or Etruscan, they belonged to the Indo-European language group, which also extended to India and Central Asia. This raises the question of when these languages, or their ancestral prototype, were first spoken in Europe. One theory links these languages with a particular population of Indo-Europeans and explains the expansion of the languages as the result of invasion or immigration; their origin is sought in the east, perhaps in the area north of the Black and Caspian seas. The invasion is associated with the new patterns of settlement, economy, material culture, burial, and social organization seen about 3000 BC. These innovations, however, may be better attributed to internal developments. An alternative explanation for the origin of Indo-European languages associates it with the immigration of the first farmers from Anatolia at the beginning of the Neolithic Period, but the spread of farming does not seem to have been a uniform process or to have been achieved everywhere by population migration. There is, however, no single archaeological pattern that might correspond to a migration on an appropriate geographic scale throughout Europe, and all these explanations raise fundamental questions about the development, spread, and adoption of languages, the relationship of language to ethnic groups, and the correspondence of archaeologically recognizable patterns of material culture to either language or ethnicity. (T.C.C.)

The Metal Ages

The period of the 3rd, the 2nd, and the 1st millennia BC was a time of drastic change in Europe. This has traditionally been defined as the Metal Ages, which may be further divided into stages, of approximate dates as shown: the Bronze Age (2300–700 BC) and the Iron Age (700–1 BC), which followed a less distinctly defined Copper Age (*c.* 3200–2300 BC). At this time, societies in Europe began consciously to produce metals. Simultaneous with these technological innovations were changes in settlement organization, ritual life, and the interaction between the different societies in Europe. These developments and their remarkable reflections in the material culture make the period appear as a series of dramatic changes.

Local developments were long thought to have been caused by influences from the eastern Mediterranean and the Middle East and by migrations. Thus it was suggested that the segmented faience beads from the rich early Bronze Age graves in Wessex were Mycenaean products or that development of bronze working in central Europe was due to the Aegean civilization's need for new bronze supplies. New methods of absolute dating, including radiocarbon dating, revolutionized the understanding of this phase in prehistoric Europe. They showed that many supposedly interdependent developments had in fact developed independently and been separated by centuries. The Metal Ages of Europe thus must be understood as indigenous local inventions and as an independent cultural evolution. There were influences from, and contact with, the Middle East, and there were some migrations of people, especially from the Russian steppes; but the Metal Ages in Europe were in general far more locally independent phenomena than had been recognized. They grew out of conditions created in the Neolithic Period and the Copper Age, followed their own trajectory in Europe, and resulted in a range of new expressions in material culture and in new social concerns.

Independent cultural evolution in Metal Age Europe

THE CHRONOLOGY OF THE METAL AGES

Changes in metal objects, in styles, and in burial rituals have been used to subdivide the period. The most basic division uses the same criteria as Christian Jürgensen Thomsen's Three Age system, in which the material used for producing tools and weapons distinguishes an age. This has resulted in a distinction between the Copper, Bronze, and Iron ages, each of which has been further divided. In temperate Europe all these subdivisions consist of relative chronologies, and in such systems synchronizations and comparisons among regions are vital. For the Bronze Age, synchronization is possible, since this was a period of long-distance contacts and trade between different regions. The period had in many ways a remarkable coherence, and it has been likened to the Common Market. On this basis a general chronological framework has been developed that, using the changes in burial rites and metal assemblages, divides the Bronze Age into either Early, Middle, and Late phases or into the Unetician, Tumulus, and Urnfield cultures. Synchronizations of the more detailed local subdivisions, which were based on typology of metal objects and cross-associations, have employed schemes of Paul Reinecke and Oscar Montelius. Oscar Montelius' chronology was developed on the basis of Scandinavian bronze objects and resulted in a division of the Bronze Age into Montelius I–VI, while Paul Reinecke used south German material to divide it into shorter time sequences known as Bronze Age A–D and Hallstatt (Ha) A–D, with Hallstatt C marking the transition to the Iron Age in central Europe.

The Iron Age chronology is detailed and regional. Although the Iron Age was a Pan-European phenomenon, its regional variability, together with its fragmented and tribalized cultural landscape, makes its chronology complex. In addition to typology and cross-association, the Iron Age chronology is also built upon historical events and Mediterranean imports of known date; the development of artistic styles also plays a major role in its subdivision. It is again central Europe that provided the most commonly used general chronology. The Hallstatt Period, named after an artifact-rich cemetery next to late Bronze and Iron Age salt mines in the Austrian Salzkammergut, is divided into Early (Ha A–B) and Late (Ha C–D) phases, with the former marking the end of the Urnfield Culture in Europe and the latter being the first phase of the Iron Age in areas such as central and southern Europe but the transition to the Iron Age in other regions. The second phase of the Iron Age, when it extended throughout Europe, is named after La Tène, a site at Lake Neuchâtel in Switzerland. The exact function of this site is not known, but it contained thousands of swords, spears, shields, fibulae, and tools. These were distinctive in shape and beautifully ornamented in a style different from that of the objects from the Hallstatt period. This, the La Tène style, was found from the 5th to the 1st century BC throughout most of Europe, and its development and change over time are the basis of the chronological division into La Tène A–D. Other evidence, such as southern imports, has increasingly become incorporated into the La Tène chronology, and the time from the end of the Hallstatt Period until the spread of the Roman Empire is divided into a number of short phases, each with distinct material expressions. The stylistic basis of this chronology stresses the common heritage, the Celtic art style, which developed over large areas of Europe during this time.

The transitions between the three phases of the Metal

Ages are primarily defined by a change in the metal used, but they also reflect economic changes and transformations of social organization. It is within these larger concerns that the character of this part of European prehistory can be found.

GENERAL CHARACTERISTICS

The Copper Age. Also known as the Chalcolithic or Eneolithic Period, the Copper Age was a time of diffuse and sporadic use of copper for a limited number of small tools and personal ornaments. If the age is defined simply as the time when copper first began to be used, then localized Copper Age cultures existed in southeastern Europe from the 5th millennium BC. On the other hand, if it is defined as the time when copper was an established element in the material culture, then it must be dated from about 3200 BC in the Carpathian Basin and southeastern Europe, slightly later in the Aegean, and later still in Iberia.

In these early copper-using societies, copper had no importance in subsistence production, and the tools made could hardly compete with those of flint and stone. The new material had prestige, however, and was used to adorn the deceased. It was at this early stage of metal use that one of its important roles was established: to mark and articulate social prestige and status. The Copper Age as a distinct stage developed only in a few regions; these included groups in areas as far apart as Bulgaria, Bohemia, the Aegean, and southeastern Spain.

Millaran Culture

One of these remarkable centres of early copper use was in southeastern Spain. Situated in the Almerian lowland, in an area confined by the coast and the mountains, it was a densely settled region with large nucleated and often fortified hilltop settlements of surprising architectural sophistication and with a rich and inventive material culture known as the Millaran Culture, after the site of Los Millares. Like contemporary sites in the region, Los Millares was located so as to overlook a river from a promontory in the foothills of higher mountains. The sides and plateau of the hill were fortified with massive stone walls, regularly placed semicircular bastions, and outlying towers. These created a well-defined and protected space of approximately 12 acres (5 hectares), with several occupation phases and of some complexity. The settlement was townlike, with rows of stone houses, alleys, and a central communal place within the walls. An artificial watercourse may have led to the settlement. There was specialization of production between households. Outside the settlement was a cemetery containing more than 100 megalithic tombs with corbeled chambers used as collective burial places.

Roots of the Bronze Age cultures

The Bronze Age. Simultaneous with such Copper Age cultures were a number of late Neolithic cultures in other regions. The Early Bronze Age had, therefore, various roots. In some areas it developed from the Copper Age, while in others it grew out of late Neolithic cultures. In western and part of central Europe, the Bell Beaker Culture continued into the Early Bronze Age. It had introduced the use of copper for prestigious personal objects, individual burial rites, and possibly also new ideological structures to the Neolithic societies over vast areas of Europe. These new elements were the basis of the transformation that took place during the Early Bronze Age and became prominent within the emerging societies.

In the rest of central and in northern Europe, the Corded Ware Culture was an important component of the late Neolithic, and some local Early Bronze Age characteristics can be traced to these roots. For example, this is seen in terms of burial rituals. Burials of the Corded Ware Culture were usually single graves in pits, with or without a barrow. The deceased was placed in a contracted position, men on their left side, women on their right, both facing south. This differentiation of body position according to sex was maintained in the earliest Bronze Age in many areas, but at times the orientation was reversed, such as at Branč, in Slovakia, where 81 percent of females were on their left side and 61 percent of males on their right. As the period progressed, grave forms began to diversify, and, though inhumation in pits remained the commonest form, it was elaborated in different ways. The position of the body became stretched rather than contracted, and sex and age were not expressed by body position but were reflected through elements such as grave goods or location within the cemetery.

The characteristics of, and the dates for, the Early Bronze Age vary regionally in central Europe. Some areas, such as the Saarland, even appear either to have had continuous Neolithic occupation until as late as 1400 BC or to have been uninhabited during the Early Bronze Age. Most of these areas were enclaves, however, and it was only in Scandinavia, where the Bronze Age began about 1800 BC, that the transition to the Bronze Age was substantially delayed for a whole region.

Such local delay of the earliest Bronze Age cannot simply be seen in terms of retarded cultural development; rather, it reflects that different cultural trajectories were followed by various societies. Scandinavia illustrates this well, since the period preceding the Bronze Age was a time not of devolution but of new flint technologies and new material forms, with a wealth of beautifully manufactured flint daggers and a conspicuous display of local craft. This constituted a distinct local Late Neolithic phase, interspersed between the Corded Ware Culture and the Bronze Age proper. The flint daggers show clear influences from bronze daggers, and examples of flint swords reflect the emulation of new ideas. This indicates the degree of contact with bronze-using societies. When bronze was introduced and incorporated into the local culture, its role in terms of the cultural manners of manufacture and behaviour was rapidly established, and it quickly reflected a distinct local tradition: the Nordic Bronze Age. At this point, the absence of local raw material did not prevent the society from integrating bronze as a basic material in its culture nor did the dependency on trade partners for bronze mean that the local material culture developed without its own distinct character. The Nordic Bronze Age illustrates the ability of local cultures to maintain their independent character in spite of dependency on other, larger systems. This characteristic can be observed in different forms throughout the Metal Ages, and, in an essential manner, this qualifies the impression of an overall common cultural heritage developing during these millennia.

Although the dates and the cultural roots of the Early Bronze Age vary, it is similarly defined by the use of copper alloys for tools throughout Europe. During the Bronze Age, the techniques of metalworking increased in sophistication. A range of new working methods, such as valve molds, cire perdue, and sheet-metal working, were developed. The development of molds made it possible both to mass-produce objects and to produce more elaborate items, including hollow objects. One of the most spectacular objects produced in this fashion was the lur, a musical instrument of great precision and beauty. The later Bronze Age and Iron Age method of sheet working facilitated the production of large objects, such as caldrons and shields, and a similar working method was used for the boss motif of bands of raised circles, which became a favoured element on many Urnfield Period objects such as horse harnesses and situlae (bucket-shaped vessels).

The manner of decorating the objects expressed regional as well as chronological styles. Among these, the most noticeable stylistic developments were the widespread use of the combined sun-bird-ship motif of the Urnfield Culture and the later break in stylistic tradition indicated by La Tène, or so-called Celtic, art. Most important, however, may be the invention of new types of objects. While objects made of ceramics, gold, stone, and organic materials during this period differed from those of previous periods, they did not represent drastic changes in the employment of a particular medium, but this was not true of bronze. Bronze is an artificial material made by alloying copper with different metals, in particular tin, through which a new material with its own distinct properties is produced. The production of bronze was an invention in its true sense, and the potentials of this material were increasingly revealed and exploited during the Bronze Age. The effect of this was a range of new objects, of which some were new shapes for old concepts but others introduced new functions and concepts into the societies.

The introduction of weaponry

Among the latter, one of the most important new elements was the invention of the sword. With the sword there was for the first time in European history an object entirely dedicated to fighting and not doubling as a tool. Fighting is evident from earlier periods as well, but during the Bronze Age it was formalized. Toward the Late Bronze Age the warrior emerged, sheathed in an assemblage of defensive items: the armour. To have been a warrior during the Iron Age must have been an established role, and the importance of warfare led to monumental defensive structures and further evolution of swords and shields. The latter development shows changes in the fighting technique, and in the Early Iron Age the stabbing sword of the Bronze Age was replaced by a heavy slashing sword, indicating fighting from horseback. The actual importance of warfare is difficult to establish, and a distinction between the symbolic representation of aggression and real aggression must be kept in mind. The presence of swords and armour does, however, represent a concrete expression of aggression and of the concept of warfare.

The increased importance of fortified settlements and villages further shows that aggression was a major component of life. Professional soldiers, as they were known at the time of the Roman Empire and the Middle Ages, are unlikely to have existed at this time, but group warfare existed from the Iron Age onward, and other related professions developed. For example, the location of fortified sites in strategic places, such as near mountain passes and river crossings, suggests that these sites were not primarily defensive but were based on the ability to control certain resources, including access and passage. This is illustrated by the rich Early Bronze Age fortified site at Spišský Štvrtok, Slovakia, strategically located to control the trade routes running through a mountain pass across the Carpathians along the Hornád River, and by the Late Bronze Age Lusatian hilltop site in the Moravian Pforte passes. The development of aggression and its formalization played a role in providing middlemen and entrepreneurs with opportunities and helped to establish them in the position of power they gained in the Iron Age.

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The multiple ramparts at Maiden Castle, an Iron Age hill fort in Dorset, Eng.

The Iron Age. During most of the Middle and Late Bronze Age, iron was present, albeit scarce. It was used for personal ornaments and small knives, for repairs on bronzes, and for bimetallic items. The Iron Age thus did not start with the first appearance of iron but rather at the stage when its distinct functional properties were being exploited and it began to supplant bronze in the production of tools and weapons. This occurred at different times in various parts of Europe, and the transition to the Iron Age is embedded in local cultural developments. The reasons why iron was adopted differed among regions, but generally a similar pattern was followed. After an introductory period, iron quickly supplanted bronze for the making of tools and weapons. It was at this stage that metal, in spite of the earlier presence of bronze tools, replaced stone, flint, and wood in agricultural production. New and more effective tools were developed during the last centuries BC, and subsistence production must have increased drastically. Along with these domestic changes, there were changes in the traditional routes of contact and trade. These routes had been established during the Bronze Age, and through them copper, tin, and other commodities had traveled throughout Europe. With the appearance of the rich Late Hallstatt communities of south-central Europe, the orientation of contact changed. The northern links were increasingly ignored, and trade became concentrated on, and dependent upon, commodities from the south. South and west-central Europe were now included in the periphery of the expanding Mediterranean civilization; and the previous network of contact was broken. In the rest of Europe, regional diversity increased, a tribalized landscape emerged, and new types of social organization developed. During the Iron Age, the roots of historic Europe were planted. Proto-urban settlements, hierarchical social orders, new ideological structures, and writing were parts of this picture. It was also a time during which the difference between the Mediterranean world and temperate Europe became even more pronounced and new degrees and forms of dependency developed in the socio-political systems.

SOCIAL AND ECONOMIC DEVELOPMENTS

Control over resources. The Metal Ages were periods of discovery, invention, and exploitation of various metals and metallurgical procedures. New elements were introduced into the societies, which played a role in their further development. In the later 5th and earlier 4th millennia BC, copper from easily worked surface deposits was used for relatively simple items in southeastern Europe and the Carpathian Basin. The Transylvanian copper ores were particularly important. For example, copper was extracted from the quarry at Varna, Bulg., about 4400 BC in an area near a rich Copper Age cemetery. After this initial exploitation, metal objects again became rare until they reappeared in the late 4th millennium BC. The reasons for this change are unknown but may in part relate to the depletion of surface ore deposits. At this early state, the technique of copper manufacture consisted of smelting in an open one-faced mold and hammering. Later, when copper of different compositions from deeper deposits was used, the properties of copper in combination with other metals were explored. The copper sulfide ores from these deep mines were more difficult to procure, since they relied on more sophisticated mining techniques and needed initial roasting before smelting. At the same time, they were more widely available than surface deposits, and there were sources in both central and western Europe—ores in Germany, Austria, and the Czech and Slovak Republics were exploited from the early 3rd millennium BC. This long initial phase of sporadic use of copper was finally replaced by a period of copper alloys, which began about 2500 BC in southeastern Europe, slightly later in the Aegean, and later still in Iberia. Bronze industries were widespread in Europe by 2300 BC, but copper-tin alloys were first used toward the end of the 3rd millennium, with renewal of the centres of metallurgical production in Austria, Germany, and neighbouring areas. The raw material needed was available only in a few regions, and tin, particularly restricted in its distribution, was found only in eastern Portugal, Sardinia, Tuscany, Cornwall, the Isles of Scilly, and the Bohemian Ore Mountains. The latter site, on the border between the Czech Republic and eastern Germany, was one of the rare instances of close proximity between copper and tin. This region, together with the copper areas of the Harz Mountains, the Alps, and central Slovakia, became one of the most important regions of the Early Bronze Age. With the progression of the Bronze Age, local metallurgical traditions developed throughout Europe, including areas lacking both tin and copper sources; but the chief metalworking centres continued to influence the

Chief metal-working centres

material culture of larger areas. This was an important factor behind the trade and exchange network that came into existence.

The discovery of iron was most likely a by-product of bronze working, and much of the earliest iron use is not culturally distinct from the use of bronze. At its early stage, iron may have been monopolized and produced by those individuals or groups who controlled bronze. Iron, however, is different from bronze in many respects. It is found widely in Europe either as iron ore or as bog iron. To be usable, iron does not need alloying with other metals, and the demands are mainly the fuel and labour needed to smelt or roast the ore. This process involves high temperatures and skilled control of pyrotechnology. To produce a usable iron, the bloom must be hammered while red-hot to reduce the impurities and to change its internal structures. Only then can the shaping of the final object begin. Thus, the production of an iron object consists of several distinct stages, each different from those involved in bronze production.

Iron appeared in Romania about 1700 BC and in Greece shortly after. During the Middle and Late Bronze Age, it occurred infrequently except in Iberia, Britain, and some other parts of western Europe. The earliest iron was used for small knives, pins, and other personal objects and for repairs on bronze items. Only in Romania was iron used for heavy tools during the Bronze Age; toward the end of the Bronze Age, tools and some weapons made of iron appeared generally in Europe. With Ha C, iron swords were being made, and, in the following La Tène Period, iron had clearly become a material important in its own right, being used for a range of new functional items, including plowshares, carpentry tools, and nails. At this point it is likely that the previous monopolies on metal production and trade were severely challenged, and iron became a common material, produced and procured anywhere in Europe.

The intensity of metal use varied regionally, and the centres of innovation and wealth moved over time. During the Metal Ages the communities of Europe can be studied through their reaction to, and adoption of, their inventions. It is a phase in prehistory that raises cultural questions about the nature of innovation and of its consequences for society. Metal brought several important new items to the communities, but, more importantly, it changed the nature of society itself. The production of bronze was an important step in human history, indicating a point at which the limits imposed by natural materials were broken by human invention. The behavioral impact of this cannot be measured, but it was likely substantial. It may have altered attitudes to nature and created the activities that resulted in deep mining of metals and salt and caused experimentation with new materials, such as glass.

Social effects of metal use

Metal also had social impact, and one of its important roles came from its involvement in the articulation of prestige and status and thus its ability to assign power. Scarcity usually implies preciousness, and control over scarce or precious resources often leads to power. The production of both bronze and iron objects involved scarcity of either resources or knowledge or both. Control of metal production was a relevant factor in prehistory, as shown by the location of important Copper Age and Early Bronze Age communities in close proximity to copper or tin ores or by the breakdown of trade alliances that occurred in the Early Iron Age. The wealth and outstanding material culture of the Copper and Early Bronze Age communities were probably related to the trade in, and prestigious value of, copper and bronze. It is also a characteristic of these communities that this wealth was not consolidated by other activities, and some of the centres were short-lived and declined quickly. The lack of ability to invest and rechannel wealth in absolute terms is one of the most basic differences between these communities and those of both the Mediterranean civilizations and the Iron Age. Only some of the Copper Age centres developed into flourishing communities in the earliest Bronze Age. Those that did remain became the Early Bronze Age centres of wealth, contact, and trade, with dense populations. These centres were widely spaced and were internally extremely different, ranging from places such as El Argar in Iberia to Wessex in southern England. Of these, the Argaric Culture in southeastern Iberia comprised nucleated village settlements similar to those from Los Millares but with even greater sophistication and with a changed funerary rite. The deceased, richly adorned with diadems, arm rings, and pins and accompanied by metal tools, were individually entombed in large funerary urns placed under the house floors. At the other extreme was the group of rich Early Bronze Age graves in Wessex. The objects found in them are comparable in wealth to the Argaric ones, and, although the exotic items were unique to each area, they shared a range of tools and some ornaments. There was essential divergence in other respects, however, and at Wessex there was no association with elaborate domestic structures. The rich graves served as the ritual centre for a dispersed community living in relatively simple constructions of wattle and daub and without demarcations of the limits of their settlements. These Early Bronze Age centres developed in different environmental zones, ranging from semiarid to lush temperate, and they are at different distances from copper ore. They all have possible links with areas containing tin ores, however, and they developed in regions that were local centres in the previous period. These two criteria may have been necessary conditions for this development; but such conditions in themselves did not result in rich centres in the Early Bronze Age, nor could they guarantee continuous survival of the centres. As in the case of the earlier Copper Age centres, these were without an additional stable foundation, and they disappeared at different rates and under varying local circumstances. Such situations were plentiful during the Metal Ages. They show not only that the scarce and prestigious resources could be controlled and could give access to power and wealth but also that a multitude of factors influenced whether that power was secured and how it was maintained.

Changing centres of wealth. Societies are dynamic structures that interact with each other. In this interaction, asymmetrical relationships frequently develop between areas or groups, with one partner assuming a central, and the other a peripheral, role. Such relations are not stable, however, and over time their internal asymmetry will change. These changes can be illustrated by two examples from the Metal Ages in western central Europe.

The first is from the Early Bronze Age, where a remarkable shift in cultural initiative took place. The earliest Bronze Age centre, Unetician A, consisted of a complex of flat inhumation graves with modest grave goods in copper and bronze that was found in Slovakia. During Unetician B this complex continued, spreading into Bohemia and much of Germany and Poland. In this process, the original centre was complemented by a number of extremely rich graves on its periphery, such as at Leubingen, Helms- Leubingen

Landesmuseum fur Vorgeschichte, Halle, Ger.



Early Bronze Age (Unetician B) gold ornaments from a grave at Leubingen, central Germany. In the Landesmuseum für Vorgeschichte, Halle, Ger.

dorf, and Straubing in central Germany and Łęki Małe in southern Poland. These graves were inhumations under large barrows, with elaborate chambers and rich grave goods. Leubingen, for example, was a 28-foot- (8.5-metre-) high barrow with an elaborately constructed 66-foot-wide central stone cairn delineated by a ring ditch. The cairn covered and protected a thatched tentlike wooden structure made of large oak planks with gypsum mortar in the cracks. The skeleton of an old man lay extended on the oak floor, and at a right angle across his hips lay another body, which appeared to be that of an adolescent or child. In the space around the deceased were a number of objects, including, a pot in a setting of stones, bronze halberds and tools, and a group of gold ornaments. These graves show that a new and radically different funerary ceremony had taken place in this area, although the material culture still remained related to that of the previous centre. Thus, this group of barrows constituted a complementary Unetician area on the periphery of the original complex, and it was from this area that much of the impetus for the development of the Tumulus Period came.

The second illustration of change in the relationship between areas is from the earliest Iron Age in southern Germany, as exemplified by the hill fort at Heuneburg and its satellite barrows and secondary sites. These sites show how the central position of southern Germany and Switzerland during the Urnfield Period was transformed in the course of the Late Hallstatt Period into a peripheral role on the edge of the Mediterranean world. Heuneburg had several occupation phases, ranging from the middle of the 2nd millennium BC to the late 1st millennium AD, but the climax of its occupation was in the 6th and early 5th centuries BC, the so-called IV phase. The site, on a promontory overlooking the valley of the upper Danube, consisted of seven acres enclosed within a defensive earthwork. During its IV phase, this defense included bastions and mud-brick walls, both of which were Mediterranean inventions. The site was densely populated, and it shows a range of activities taking place at the interior in workshops for bronze, iron, antler, and coral. Among the imports were Black-Figure shards from Greece, an Etruscan clay mold, and wine amphorae from a Greek colony in southern France. Some of the local pottery, which was among the earliest wheel-thrown pottery in central Europe, shows imitation of Greek ornamentation from southern France, while other examples copy Etruscan bronze vessels.

On the plateau behind Heuneburg are several large barrows with multiple burials, which are among the largest and richest in Europe. There were a number of farmsteads between these and the hill fort itself. This association between an important hill fort and rich graves for male and female leaders was present at other places during the 6th and early 5th centuries BC, particularly in eastern France, Switzerland, and southwestern Germany. Examples include the Hohenasperg oppidum and the rich burials at Kleinaspergle, in southern Germany, and the Mont Lassois oppidum in eastern France and the Vix grave. The latter contained a five-foot-high bronze wine krater of Greco-Etruscan workmanship, a gold diadem, and an exquisite bronze statuette, together with wine-drinking equipment, Greek pottery, a vehicle, and other ornaments. The complexity of the structural buildup in the landscape surrounding these hill forts is amazing. Many of the sites had several phases of occupation but, as with Heuneburg, the Late Hallstatt Period is a distinct phase, and the brief time it took for these centres to come into existence demonstrates the potential for power available at the time. Heuneburg was one of the wealthiest of all these sites, and it is important for many reasons. It provides evidence of emulation of another culture, and it clearly demonstrates the changes in its position vis-à-vis a number of cultural systems. This is shown most clearly in the construction techniques used in phase IV, which copied both plans and building techniques from Greece. The mud bricks were totally unsuited to this part of Europe, but they show the importance of the Mediterranean culture during this period, as does the adoption of wine-drinking ceremonies. Through these evidences of emulation, Heuneburg stands as a key site for appreciating the changes in the Early Iron Age in the relationship between the classical world and the rest of Europe.

The exceptional concentration of Late Hallstatt chieftain burials on the upper Danube and upper Rhine lasted only to the beginning of the 5th century BC, when decentralization set in, but it had played a role in a period when relations within Europe were transformed. During the Bronze Age, Europe was roughly divided into two worlds: the eastern Mediterranean and temperate Europe, each with a common cultural heritage. With the Iron Age, the fragmentation and diversification of temperate Europe began, while the eastern Mediterranean expanded through a burst of colonial activities that resulted in cultural dominance over an extended but internally diverse area.

Diversification of temperate Europe

Prestige and status. The Neolithic was a period of remarkable communal enterprises. Against this background, the emphasis that the Bell Beaker and Corded Ware cultures placed on the individual constituted a radical change. The British archaeologist Colin Renfrew characterized the change as one from "group orientation" to "individualized chiefdom," and this change was essential for the emerging Early Bronze Age communities. In the Late Neolithic, collective burials disappear from European prehistory in favour of individual graves. The form of the grave and the character of the funerary ceremonies changed substantially during the Bronze and Iron ages. The common and widespread use of cremation introduced by the Urnfield Culture is an important indication of the potential for radical changes within this realm. Throughout the period, the individual remained the focus of the funerary ceremony, and the evidence suggests that prestige and status often were communicated through the wealth and types of objects found in graves. It is debated whether the differences between individuals that this suggests were classlike and absolute, were expressions of sex, age, and lineage differentiation, or were assigned through deeds rather than ascribed at birth. The changes through time suggest increased social differentiation, but there also are periods, such as the Urnfield Culture, in which social differentiations are less obviously expressed in graves. The grave can, therefore, be used mainly to establish relative differentiation within one community rather than pronouncing absolute historical trends. One such study comes from the cemetery at Branč, where 308 inhumation graves spanning 200 to 400 years of the early Unetician Culture were analyzed. Within the graves there was clear evidence of internal differentiation, with some individuals having more elaborate grave goods than others. This suggests that in this type of community there would be leading families, marked by their grave goods, and that wealth and status would tend to be inherited through the male line (since male children had richer grave goods than female children). Females obtained rich costumes during adolescence and young adulthood, possibly at the time of their marriage. The status expressed at this period was to a large extent relational, placing each member of the community according to lineage, sex, and age. This differentiation was not directly based on access to power, possessions, or absolute wealth, and, in most areas of temperate Europe, social differentiation until the 1st millennium BC was likely moderate. The exception to this was short-lived local expressions of individual wealth or, more likely, prestige, such as the Wessex graves and the Leubingen-Helmsdorf group, since they suggest single leaders occupying sociopolitical roles, which were symbolized through emblems of power.

Throughout the Bronze Age, sex and age were the main components organizing the structures of daily life. Outside the Mediterranean area, there were few differences between the size and plan of most of the structures within individual sites, although the sites within a region often were internally ranked in terms of size and complexity, which suggests that they had different functions. Such "tiered" settlement systems came into being in the Early Bronze Age in areas such as southeastern Europe, and they were quite prominent during the Late Bronze Age in the Lusatian Culture of Poland and northeastern Germany as well as in the Urnfield Culture of central Europe. This settlement organization probably continued into the Early Iron Age in some regions, such as England, where

"Tiered" settlements

the hill forts became central places for an agricultural, and possibly also political, upland.

A clear social and political hierarchy was, however, lacking from the Bronze Age settlement pattern. This was particularly true of northern, western, and central Europe, which saw a variety of settlement organizations during the period. There were extended farmsteads in northern and western Europe with a development of enclosed compounds and elaborate field systems in Britain. In central Europe the extended farmsteads were in time supplemented by both unenclosed villages and defended hilltop sites, as was also the case in the area of the Late Bronze Age Lusatian complex in Poland and neighbouring areas. The fortified settlements were usually large planned enterprises, rather than organic village sprawl, and they were often erected over a few years; an example is the Lusatian defended settlement at Biskupin, Pol., where a settlement of 102–106 houses estimated to shelter some 1,000 to 1,200 people was built in just one year. The fortified sites and enclosed villages of the European Bronze Age show centralized decision-making and capacities for planning and constructing grand enterprises. Their concern was the whole community rather than the individual household, and communal features such as paths, gates, and wells were well maintained and planned. The superbly preserved Late Bronze Age sites from the Swiss lakes show these communities vividly. The settlement at Cortallois-Est, on Lake Neuchâtel in Switzerland, illustrates the main features of such sites: straight rows of equal-sized houses aligning paths and alleyways, with the whole complex contained within a perimeter fence. Each house had a fireplace with a decorated house-alter, or firedog. The rubbish accumulated in front of the entrance, and various activities took place within the house. The sites were densely inhabited, and minor internal differences of objects and structure existed between the houses; but they were not divided into different classes in terms of their wealth, size, or accessibility, although different crafts and trades may have made up quarters within the village. These Late Bronze Age villages did not contain any structures that could be interpreted as administrative centres or as religious offices.

A different form of organization is found throughout the Early Bronze Age in southeastern Europe and in southeastern Spain. Both areas had nucleated defended settlements during this period, and there appears to have been some differentiation of the houses in terms of function and size. A tendency toward centralization is demonstrated by the Early Bronze Age site at Spišsky Štvrtok. This was a fortified site of economic, administrative, and strategic importance. An oval area, enclosed by a ditch and rampart, was differentiated into an acropolis and a settlement area, with the houses of the acropolis built using a different technique. The amount of gold and bronze objects hidden in chests under the floors of the houses in the settlement area further suggests that there were economic and social distinctions among the inhabitants.

Early Aegean civilization

The important exception to this picture is the eastern Mediterranean, which underwent a rapid and dramatic social development during this period, permanently severing its cultural affinity with temperate Europe. At a time of modest stratification in the rest of Europe, the first European civilization—as defined by administration, bookkeeping, writing, urbanism, and the separation of different kinds of power—arose in the Aegean. Its background was the Neolithic cultures of the 3rd millennium BC, which were closely aligned with those of temperate and southeastern Europe. The Neolithic roots alone cannot explain the development in the Aegean, and there is no convincing evidence for external influences behind these changes in Greece nor is there basis for arguing for a migration. Local factors must have caused development to follow a different route in this area.

One of many possible factors was the marked population increase in the south Aegean during the Early Bronze Age. This led to the development of some extensive settlements, although the overall settlement pattern continued to be dispersed, with a majority of small hamlets and farmsteads. This could have caused a degree of settlement hierarchy at this stage, with some sites acting as regional centres. Central places provide opportunity for craft specialization and redistribution of commodities and thus lead to social hierarchy and a type of society known as the complex chiefdom. Another important factor was the change in agricultural production that followed the adoption of vine and olive cultivation during the 3rd millennium BC and the possible increase in the exploitation of sheep. These were commodity-oriented activities, which furthered exchange and redistribution. These products were more suitable for a redistributive economy than for a household economy. Olives, in particular, demand capital investment, since it takes several years before the crop produces. Within this setting, the palace economy, a complex bureaucratic organization based on a redistributive economy, developed. The first state had appeared in Europe.

This process can be followed from 1800 BC onward in Mycenae, in mainland Greece, and on Crete. The character of the society was distinct at each of these centres, but the palace economy distinguished them from the villages and farmsteads of temperate Europe. For reasons not clearly known but possibly related to subsistence crises and over-exploitation of dwindling metal supplies, these centres collapsed suddenly about 1200 BC, and thereafter Greece entered its Dark Ages. After a few centuries of restructuring, about 800 BC this was followed by a remarkable Greek expansion into the western Mediterranean, during which colonies were founded in southern Italy, Mediterranean France (Massalia), and along the southeastern coast of Spain. The Etruscan state, which developed in Italy from about 700 BC, competed for domination of the western Mediterranean, and during the Early Iron Age Etruscan as well as Greek influences reached beyond their Mediterranean neighbours.

During the Iron Age, stratification became common and marked throughout Europe. Differences in wealth and status in terms of both individuals and households were reflected in graves as well as settlements. Settlements reveal internal division of houses according to size and function, and the population of any village was divided by wealth in addition to sex, age, kinship, and personal characteristics. Socially differentiated settlements existed from Scandinavia to Italy and from Ireland to the Russian borders, although they were differently laid out and organized. This period saw the building of permanent fences and enclosures around fields and farms; the development of villages and, within these, increasing differentiation of the sizes of individual buildings; and increased stratification between settlements, with proto-urban centres coming into being. The rate of change varied in different parts of Europe, but toward the end of the 1st millennium BC all areas had undergone these changes. The end of this trend in northern Europe is vividly illustrated by the Hodde village in Denmark, where the community can be followed during the centuries near the end of the 1st millennium, revealing how a few farms within the enclosed village gradually grew bigger at the cost of the others. An unstratified village was replaced by a society divided into rich and poor in only a few centuries. In other parts of temperate Europe, social division was equally clearly present, and proto-urban characteristics such as commerce, administrative centres, and religious offices came into existence on some of these sites. In this process, the defended hilltop settlement of the Early Iron Age was increasingly replaced by more complex sites.

The oppida

The proto-urban tendencies are particularly strongly suggested by the oppida of western, central, and eastern Europe. These were often densely populated enclosed sites, which housed full-time specialists, such as glassmakers, leather workers, and smiths. Manching, one of the largest oppida in Europe, contained many of these characteristics. The site, located at the junction of the Danube and the Paar rivers, was occupied from about 200 BC and developed rapidly from a small undefended village to a large walled settlement. The defense was an elaborate construction consisting of four-mile-long walls built of timber and stones and including four gateways. Some areas within the defense were never occupied but others (a total of about 500 acres) were densely settled. The organization of

the settlement was preplanned, with streets up to 30 feet wide and regular rows of rectangular buildings in front of zones containing pits and working areas; other areas were enclosed for granaries or the stalling of horses. The site was divided into work areas for particular crafts, such as wood, leather, and iron working. Coins were minted and used on the site, and there is evidence of much trade.

A market economy, rather than a redistributive economy, is the hallmark of these sites, and they were important supplements to the regionally dispersed smaller villages and farmsteads. Commodities became direct wealth, and the exchange of different values was monitored through coins. A drastically altered society was the result, but the Roman expansion at the end of the 2nd century BC caused major changes and brought local development to an end. The Romans established their own towns and a new system of government, and the oppida were not given the opportunity of developing on their own into towns, for which they had laid the ground.

The beginning of the Iron Age was in many areas marked by change in burial rites. The extensive use of cremation during the Urnfield Period was replaced by inhumation graves with magnificent displays of wealth. During the Late Hallstatt Period these changes were most dramatically reflected by the group of so-called princely graves in west-central Europe. These were immensely rich burials in large barrows, in which the construction of grave chamber and barrow became monumental enterprises, reminiscent of the late Unetician barrows at Leubingen and Straubing. In each case the grave was a display of power and status, giving emphasis and prestige to an individual or a lineage at a time of overt disruption of the social order. One of these rich Hallstatt graves was Hohmichele, located within the complex around Heuneburg on the Danube. This barrow was one of the satellite graves surrounding the large hill fort. It covered a central grave and 12 secondary burials. The barrow was constructed in several stages, resulting in a large imposing monument on the level land behind the hill fort. The central grave was robbed in antiquity, but it had been an inhumation grave within a wood-lined chamber, which acted as the display area for the wealth of the deceased. The walls seem to have been draped in textiles with thin gold bands, and the deceased, dressed in finery including silk, was placed on a bed next to a four-wheeled wagon. These graves, while commemorating members of the society in a traditional way, also show new elements that had become part of the life of the nobility north of the Alps. The drinking set suggests the adoption and importance of the Greek drinking ceremonies, using the Greek jugs and *Schnabelkannen* ("beaked pots") for pouring and serving wine, the kraters for mixing, and the amphorae for storage and transport. The implied wine-drinking ceremony, which was likely restricted to certain sectors of the society, and furniture directly imported from the south show the emulation of southern city life by the central European chiefs.

The rich princely graves were constructed in southwestern Germany during Ha C–D. Thereafter inhumation graves became more widespread in central Europe and neighbouring areas, and they were the main burial form until the 2nd century BC, when formal burial rites disappeared in many regions and cremation was reintroduced in others. The graves of the early La Tène Period remained very rich, but barrows and elaborate grave chambers ceased after their resurrection by the Hallstatt princes and princesses. Regional variations in rites and assemblages became prolific. In France, La Tène cemeteries contained rich flat graves that had two-wheeled wagons rather than the earlier four-wheeled ones. These graves held large amounts of beautifully manufactured Celtic objects such as swords and torques, as well as Roman and Greek imports, and there were clear distinctions drawn between the sexes. In central and eastern Europe a new regional complex had developed northwest of the Black Sea, in which there were both inhumation and cremation graves clustered in large cemeteries. This complex is often attributed to Scythian invaders, and the rich assemblages and warrior graves show their influence. In the area of the lower reaches of the Dnepr, Dnestr, and Don rivers, rich Scythian graves have been excavated in the form of shaft and pit graves; in these, the deceased was accompanied by a number of other humans and by horse burials. In northern Europe and Scandinavia, cremation in large urnfields continued during most of the Iron Age. In this area the social differentiation present in the settlements and the wealth displayed by a few large hoards were not expressed in the graves, and, while large numbers of the population were given formal burials, their social statuses were not explicitly expressed in this ritual. Roman and Greek imports and wine-drinking ceremonies also reached northern Europe, but it was not until the end of the Iron Age, when formal inhumation burials reappeared, that they were being used in ways similar to those in more southerly regions.

La Tène grave goods

In Britain the sequence is even more complicated and shows both a strong indigenous tradition and clear local influences from western Europe. The greatest complication is the disappearance of formal burials in this area in the Late Bronze Age; they did not reappear before the last century BC and then only in a few regions, such as Yorkshire. The Late Iron Age inhumation graves in Yorkshire are almost identical to wagon graves in northern France, and there must have been very specific and personal contacts between the two areas to account for this.

Social differentiation existed throughout the Metal Ages but changed with time and in degree. This was not, however, a smooth process that can easily be followed through the centuries. There were odd kinks in the progression from the minimal ranking of the earliest Bronze Age to the proto-urban state of the Late Iron Age. There were also spatial variabilities and a number of different factors involved in the progression toward greater social complexity. Throughout the Metal Ages in Europe, new social institutions came into being and the relationships between people changed.

The relationship between nature and culture. During the Middle Bronze Age, the landscapes of most parts of Europe were filled in. Nature became cultivated, and this had costs. It seriously affected social organization as the population spread over larger areas and adapted to local conditions. It also affected the environment, which during the later part of the Bronze Age began to change. This was in part due to climatic changes, but it was furthered by human activity. There was overexploitation of marginal lands; people had moved onto the dunes in areas such as Poland and The Netherlands and into the uplands of Britain, France, and Scandinavia. But, even on less marginal land, centuries of agricultural exploitation began to exact a price. Many areas in southeastern Europe were extensively overpopulated in comparison with their agricultural capacities in the Copper and Early Bronze ages. In Hungary, for example, the area around the large Early Bronze Age tell at Tószeg was so densely occupied that the villages were within sight of each other. Overpopulation and overexploitation caused peat formation to begin, heathland to expand, blanket bog to grow over established fields and grazing grounds, and fields to turn into meadows. How the people reacted to this is not known in detail, nor is it easy to establish the rate of change, but it is possible to detect a number of changes during the end of the Bronze Age and the Early Iron Age that were associated with the strained economic and ecological conditions. These changes in the environment were not, as previously believed, an environmental catastrophe, but humans had influenced their surroundings to such an extent that they had to change their way of life in order to live with the consequences.

Rituals, religion, and art. Throughout this period there were vivid and striking manifestations of religious beliefs, ritual behaviour, and artistic activities. One of the most remarkable phenomena was hoarding. Objects, usually in large numbers, were deliberately hidden in the ground or deposited in water in the form of a hoard. Hoards were known in a modest form during the Neolithic Period, and in some areas, such as Scandinavia and France, there continued to be a few large hoards in the Iron Age; but it was in the Bronze Age that hoarding became a common phenomenon of great social and economic importance.

Hoarding

The contents of the hoards varied; they ranged from two to several hundred items or consisted of only one deliberately deposited object, such as the single swords found in the River Thames. They might contain several objects of the same type or of many different types. They were commonly placed in association with wet areas—such as rivers, bogs, and meadows—or located under or near large stones, including in old megalithic tombs. They were seldom parts of settlements, but they have been found in wells, such as at Berlin-Lichterfelde, in Germany. They also may have come to function as a foundation deposit for a later settlement, as was the case at Danebury, in southern England, where an Iron Age hill fort was placed at the location of a Late Bronze Age hoard. Hoards were relatively infrequent during the earliest part of the Bronze Age, when they were found mainly in southeastern Europe, Bavaria, and Austria and contained flat axes and neck rings. Hoarding reached its peak during the later part of the Early Bronze Age and the Middle Bronze Age, when the activity spread throughout Europe and became an established phenomenon in most of its communities. In the Middle and Late Bronze Age, large numbers of hoards were deposited, and a substantial number of bronze objects were in this way consumed and withdrawn from circulation. Late Bronze Age hoards from Romania, among the largest ever, contained up to four tons of bronze objects. At the same time, large collections of unused tools, newly taken from their molds, were deposited together in France.

Hoarding is one of the more unusual elements of Bronze Age Europe, and it is difficult to explain. The activity consumed large parts of the wealth of these societies without apparent benefits. Traditional explanations have divided them into different types with varying function. The lack of settlement association means that they were not originally foundation deposits, such as are known from the Roman period. They must, therefore, be explained either in terms of metalworking procedures or as having a ritual or religious meaning. Hoards that could have been retrieved from their hiding place have been interpreted, depending on their contents, as hidden treasure, merchants' stock, or items intended for recycling by the smiths. Hoards that could not possibly have been retrieved must have had ritual or religious significance, or, alternatively, they were acts of conspicuous consumption of wealth in a potlatch ceremony. This would enhance the position of the owner and, incidentally, would also ensure the flow of imports and the value of bronze. But a functional interpretation of hoards as a kind of stock cannot account for why these hoards were so often not retrieved. Thousands of hoards were made during the Bronze Age, and enormous riches were disposed of through these activities. In spite of their internal differences and variations in terms of location, composition, and amounts, it is likely that ritual behaviour and cultural meaning were always major components of this practice. There is, however, only little indication of what that meaning was. The association with water, which became more pronounced through time, could suggest water-related rituals and has been interpreted as relating to fertility rites and agricultural production. Because the location and composition of hoards vary locally as well as through time, however, they may embody more than one meaning.

Only a few areas saw instances of hoarding in the Iron Age, and their forms were distinctly different from those of the Bronze Age. The most obvious example is the votive deposit at Hjortspring, Den., where a large wooden boat equipped for war with wooden shields, spears, and swords was destroyed and deposited in a small bog. The events behind these hoards were known to classical writers such as Tacitus and Orosius, who gave accounts of war offerings by Germanic and Cimbrian tribes, respectively. They describe how the weaponry confiscated in war was destroyed and deposited in victory ceremonies. The Iron Age hoards of northern Europe had clear associations with war, the types and numbers of objects deposited together are incomparable with the Bronze Age hoards, and the ritual destruction of the entire assemblage was a new element.

The new hoarding ritual contained elements of conspicuous consumption, but its form and focus were different from previous activities. It developed shortly before the end of the 1st millennium, and it continued as a tradition among the Germanic tribes in northern Europe for several centuries. Another area with complex ritual ceremonies during the Iron Age is France. There are not many of these ritual places, but those that existed were large complex sanctuaries with continuous use over several centuries. One of these sites is Gournay-sur-Aronde, in northern France, a sanctuary used from 300 to 50 BC. The site consisted of a square enclosed by a ditch and palisade with a number of large pits for exposing and displaying offerings at its centre and a number of wood-lined ditches along the edges. In the ditches were found the remains of hundreds of iron weapons, all deliberately and systematically destroyed, as well as fibulae and tools. There were also the remains of 208 animals and 12 humans. These remains indicate some of the ceremonial behaviour that had taken place on the site. All cattle had the muzzle cut off during offering, and their skulls were displayed on top of pits and ditches. The humans had been beheaded, and the bones were at some points moved from the central pits to the ditches and rearranged there according to different prescriptions. The archaeology shows that both the Bronze and Iron ages were periods of specific and unique ritual behaviour but also that their beliefs and norms were not uniform throughout each period. As the socioeconomic structures of these societies changed, their ideological structures underwent transformation.

Evidence of ceremonial behaviour at Gournay-sur-Aronde

Societies reveal themselves through their art. These expressions are, however, difficult to interpret, and much of this evidence from the past has disappeared. It is at the same time an essential source, giving insight into the artistry and sophistication of the people of these periods. The development of styles can be followed through the decoration of metal objects and ceramics, while a more distinct pictorial art is found in the rock art from many parts of Europe, in the wall paintings from Minoan Crete, and in the odd figures and scenarios engraved on a range of materials. Stylistic developments show the existence of workshops and schools, and the degree of influence they exercised reached into far corners of the Bronze and Iron Age communities. In the stylistic development during the Metal Ages, two phenomena are of particular interest. The first is the development of the sun-bird-ship motif of the Urnfield Culture. The origin of this motif, which featured bird-headed ships embellished with solar disks, is not known, but over a short period about 1400 BC it became common both as incised decoration and as plastic art throughout a vast area of eastern and central Europe. The similarity in execution and composition is remarkable and suggests a shared understanding of its meaning and the intensity of contact between distant areas.

The second point of interest is the change in style between the Hallstatt and La Tène periods. Throughout the Bronze Age and the Late Hallstatt Period, there were two distinct types of decoration in temperate Europe: the dominant geometric design of various compositions, including curvilinear styles, and the less common naturalistic style portraying humans and animals and used, for example, in rock art. At the end of the Hallstatt Period, at the beginning of the second phase of the Iron Age, a new decorative style, the La Tène style developed, and it rapidly replaced the geometric decoration. This style, as abstract as the Bronze Age one, was nonetheless substantially different. It incorporated flowing curved lines of floral designs with zoomorphic motifs filling the surfaces of the objects and increasingly used settings of semiprecious stones and coral. During the Iron Age this style flourished and branched out into different schools of great beauty. The style reached its mature form in the 4th century BC with the Waldalgesheim style, and, after this point, its most interesting branch was found in Britain, which saw a very individual development and where La Tène art continued to flourish after this style had passed its zenith on the Continent. The La Tène style was used on a variety of artifacts, such as gold and silver jewelry, swords and scabbards, shields inlaid with enamel, bronze mirrors, and beautifully executed containers in wood and ceramics.

La Tène, or Celtic, art

The origin and spread of the different art styles have been the subject of much debate. Early Bronze Age geometric and linear motifs, in particular the use of double-axe and spirals motifs, looked to be the result of Mycenaean influences. The art of the Urnfield Culture was thought to be the result of an invasion of people from the east, bringing cremation and a new art style into Europe. La Tène art was associated with the Celtic people, and their spread throughout large parts of Europe was assumed to have brought this art to different areas. The genesis of the various artistic developments cannot easily be established; but they were not as unified a phenomenon as has been assumed, and local variations are prolific. Different art styles influenced each other and were spread widely through copies, exchange, and communication; but this was interspersed with periods of greater local diversity and less desire for contact and emulation.

THE PEOPLE OF THE METAL AGES

The Iron Age is often seen as the time of the appearance in history of the European peoples, the "barbarians" as they were seen by Rome. These people included a number of different tribes and groups, the configuration of which changed over time; all had more or less obvious roots in the Bronze Age. Ethnicity is not easy to establish, however, and the fact that, for example, the Romans ascribed an area to a particular people does not necessarily mean that those inhabiting that area constituted an ethnic and linguistic group. Continuous changes in the composition of tribal formation occurred in the Iron Age as groups bound together through alliances created by gift giving, trade, and aggression. From Greek, and later Roman, writers and from Assyrian texts, historical information about some of these people has been preserved. The main groups presented by these texts are the Celts in western Europe, the Germanic people of northern Europe, the Slavs from eastern Europe, and Cimmerians, Scythians, and, later, Sarmatians coming into southeastern Europe from the Russian Steppe. The texts describe what to their authors appeared as barbarous customs in cultures they did not understand, but they also provide historic insights into the movements of different peoples and tribes during this unrestful period.

It was also during the Iron Age that individually named people appeared for the first time in European sources, and the names of kings, heroes, gods, and goddesses have become known through legendary writers such as Homer. In the main, however, the Metal Ages were before literature began to immortalize individuals, and in general little is known about individual people or even groups from these periods. It remains up to the archaeologist to explain how the people lived and who they were, since they are known only through their art, their actions, and their own physical remains. Their art shows the people through figures and drawings, but always in a stylistic or symbolic way rather than as portraits. This is even the case in the wall paintings from Mycenaean Crete, which show detailed full-figure drawings of women and men in different costumes and involved in various, presumably partly ceremonial, activities. The figurative representations, whether drawings or statues, do not give accurate insight into the appearance, health, and mentality of these people, but evidence of this is provided by their physical remains and the things they made and used.

Their appearance can to some extent be reconstructed on the basis of skeletal materials from graves. Owing to changes in burial rites, these are better preserved from some periods than others, but in general there is good evidence. The people were close to the same height as people living today and were of a similar build. In some areas, as demonstrated by the Early Bronze Age cemetery at Ripa Lui Bodai, in Romania, people of different racial characteristics were buried in a similar manner within one cemetery, suggesting that the population was racially mixed. It is quite likely that such mixture was common in many areas, suggesting that the cultures correspond to social structures rather than ethnic or racial ones.

Physical characteristics

The mortality rate was high, and the average life expectancy was about 30–40 years, with high infant mortality and few very old members of society. At the Unetician cemetery at Tornice, Pol., the average age at death for men was 31 and for women 20, while that from the Early Bronze Age cemetery at Lerna, Greece, was 31–37 for men and 29–31 for women. Women would have given birth at an early age, and their lower life expectancy was likely due to death in connection with pregnancy or childbirth. The difference in life expectancy may be indirect evidence of girl-child infanticide. Generational time would have been short, and the nature of society was therefore drastically different. As an example, the estimate of the living population at Branč suggests that it consisted of 30 to 40 people, half of them children. This would have influenced social life, kinship systems, and subsistence activities. The bodies often show signs of heavy physical labour, and the wear on the bones suggests that many activities took place in a squatting position.

Generally, social divisions of labour and resources did not in the Bronze Age reach such degrees that this affected the bodies, but this changed with time. Analysis of the human bones from the Early Iron Age cemetery at Mount Magdalenska, Slovenia, shows such divisions. The males of some clans or leading families had more access to animal products than any of the other members of the community, and the women generally had a more restricted and homogeneous diet. With the advent of the Iron Age, the society had become so differentiated that some people lived a life protected from hard labour and physical toils while others worked extensively and had a poor diet.

Throughout the Metal Ages, humans were victims of various diseases, such as rheumatism and arthritis, which complicated life and crippled the body. Tuberculosis also has been observed, as have periodontal disease, caries, and bone tumours. Some of these diseases caused joint changes or vertebral deformities—such as were seen on a Copper Age skeleton found in Hungary—which resulted in restricted working and even walking capacities for the individual concerned. Badly crippled and handicapped people often survived, and they must have been taken care of and fed by other members of their community.

There is also evidence to suggest that people took great care with their appearance. The hairstyles were often sophisticated, with braids, hairnets, and ornaments being used by women or with the hair cut straight at the shoulder in a bob as for the girl in the grave at Egtved, Den. Manicure equipment was common in Late Bronze and Early Iron Age graves, and the mirror was a favoured object among both the Celtic people and Scythian warriors. These objects and evidence from well-preserved graves show people as well-groomed individuals who shaved regularly, braided or cut their hair, and had well-cared-for, manicured hands.

In addition to how the people looked, there is also evidence of the clothing and ornaments they used. There are a few scattered wool textiles from the Neolithic, but the first well-documented evidence of wool textiles dates from the Bronze Age. At times the textiles themselves have been found, but more commonly it is the equipment used in textile production that shows their presence. Spindle whorls, loom weights, and combs became increasingly common components of settlement debris, showing weaving as a household task performed at any settlement. With the Iron Age, new weaving techniques developed, and embroideries, dyes, and more complicated designs were introduced, as were textiles of materials such as linen and silk. At this point, it also became common to have specialist weavers, and in some oppida the weavers lived in certain designated quarters within the settlement. The increase in textile production meant that the raising of sheep intensified in many regions during the Bronze Age. In the Aegean, this happened early in the Bronze Age, and Linear B tablets that give accounts of trade in textiles certify the economic importance of this commodity for this area. In other parts of Europe, it took a little longer, but, toward the end of the Bronze Age, changes in the fleece of sheep in England demonstrate how substantially the use of sheep had grown.

Clothing and personal ornaments

Remains of Bronze Age costumes are limited, but they show various relatively simple wool garments adorned

with bronze ornaments and attachments. In many areas, hats of different kinds—possibly with a clear distinction in style between those worn by men and women—were used. Bronze statues show similarly prominent headpieces, and they often gave great attention to depicting hairstyles. In the course of the Early Bronze Age, pins became common elements of costumes, and with the Tumulus Culture they became prominent pieces, at times exceeding 12 to 16 inches (30 to 40 centimetres) in length, with elaborate heads that often reflect regional patterns. At this time, the pins lost much of their original functional role and became primarily display items. Their regional diversity suggests how people used elements of their dress to express their group identity. During the Late Bronze Age, the pin remained in use and of importance. Thousands were found in the Swiss lake sites, but these are small elegant pieces that at times were composed into complex breast pieces by connecting chains and pendants. Iron Age textiles are found much more frequently, and clothing at that time became an elaborate and colourful medium of regional and social variability. Metal attachments became less common; but the fibula (a brooch resembling a safety pin) replaced the pin, and it became an object of fashion widely adopted and undergoing much regional development and elaboration.

These were the people who lived with and created the Metal Ages of prehistoric Europe. The conditions of their lives had undergone considerable changes during the centuries of the Copper, Bronze, and Iron ages; but these were gradual changes initiated and managed largely internally and at a rate dictated from within. Roman expansion into temperate Europe during the last centuries BC changed this, and new social and ideological structures were imposed from above upon local communities. Long-established links of contact and previous cultural affinities were broken, and a new Europe came into being.

(M.-L.S.S.)

Greeks, Romans, and barbarians

The main treatment of classical Greek and Roman history is given in the article GREEK AND ROMAN CIVILIZATIONS, ANCIENT. Only a brief cultural overview is offered here, outlining the influence of Greeks and Romans on European history.

GREEKS

Of the Indo-European tribes of European origin, the Greeks were foremost as regards both the period at which they developed an advanced culture and their importance in further evolution. The Greeks emerged in the course of the 2nd millennium BC through the superimposition of a branch of the Indo-Europeans on the population of the Mediterranean region during the great migrations of nations that started in the region of the lower Danube. From 1800 BC onward the first early Greeks reached their later areas of settlement between the Ionian and the Aegean seas. The fusion of these earliest Greek-speaking people with their predecessors produced the civilization known as Mycenaean. They penetrated to the sea into the Aegean region and via Crete (approximately 1400 BC) reached Rhodes and even Cyprus and the shores of Anatolia. From 1200 BC onward the Dorians followed from Epirus. They occupied principally parts of the Peloponnese (Sparta and Argolis) and also Crete. Their migration was followed by the Dark Ages—two centuries of chaotic movements of tribes in Greece—at the end of which (*c.* 900 BC) the distribution of the Greek mainland among the various tribes was on the whole completed.

Mycenaean civilization

From about 800 BC there was a further Greek expansion through the founding of colonies overseas. The coasts and islands of Anatolia were occupied from south to north by the Dorians, Ionians, and Aeolians, respectively. In addition, individual colonies were strung out around the shores of the Black Sea in the north and across the eastern Mediterranean to Naukratis on the Nile delta and in Cyrenaica and also in the western Mediterranean in Sicily, lower Italy, and Massalia (Marseille). Thus, the Hellenes, as they called themselves thereafter, came into contact on all sides with the old, advanced cultures of the Middle East and transmitted many features of these cultures to western Europe. This, along with the Greeks' own achievements, laid the foundations of European civilization.

The position and nature of the country exercised a decisive influence in the evolution of Greek civilization. The proximity of the sea tempted the Greeks to range far and wide exploring it, but the fact of their living on islands or on peninsulas or in valleys separated by mountains on the mainland confined the formation of states to small areas not easily accessible from other parts. This fateful individualism in political development was also a reflection of the Hellenic temperament. Though it prevented Greece from becoming a single unified nation that could rival the strength of the Middle Eastern monarchies, it led to the evolution of the city-state. This was not merely a complex social and economic structure and a centre for crafts and for trade with distant regions; above all it was a tightly knit, self-governing political and religious community whose citizens were prepared to make any sacrifice to maintain their freedom. Colonies, too, started from individual cities and took the form of independent city-states. Fusions of power occurred in the shape of leagues of cities, such as the Peloponnesian League, the Delian League, and the Boeotian League. The efficacy of these leagues depended chiefly upon the hegemony of a leading city (Sparta, Athens, or Thebes), but the desire for self-determination of the others could never be permanently suppressed, and the leagues broke up again and again.

Leagues of cities

The Hellenes, however, always felt themselves to be one people. They were conscious of a common character and a common language, and they practiced only one religion. Furthermore, the great athletic contests and artistic competitions had a continually renewed unifying effect. The Hellenes possessed a keen intellect, capable of abstraction, and at the same time a supple imagination. They developed, in the form of the belief in the unity of body and soul, a serene, sensuous conception of the world. Their gods were connected only loosely by a theogony that took shape gradually; in the Greek religion there was neither revelation nor dogma to oppose the spirit of inquiry.

The Hellenes benefited greatly from the knowledge and achievement of other countries as regards astronomy, chronology, and mathematics, but it was through their own native abilities that they made their greatest achievements, in becoming the founders of European philosophy and science. Their achievement in representative art and in architecture was no less fundamental. Their striving for an ideal, naturalistic rendering found its fulfillment in the representation of the human body in sculpture in the round. Another considerable achievement was the development of the pillared temple to a greater degree of harmony. In poetry the genius of the Hellenes created both form and content, which have remained a constant source of inspiration in European literature.

The strong political sense of the Greeks produced a variety of systems of government from which their theory of political science abstracted types of constitution that are still in use. On the whole, political development in Greece followed a pattern: first the rule of kings, found as early as the period of Mycenaean civilization; then a feudal period, the oligarchy of noble landowners; and, finally, varying degrees of democracy. Frequently there were periods when individuals seized power in the cities and ruled as tyrants. The tendency for ever-wider sections of the community to participate in the life of the state brought into being the free democratic citizens, but the institution of slavery, upon which Greek society and the Greek economy rested, was untouched by this.

In spite of continual internal disputes, the Greeks succeeded in warding off the threat of Asian despotism. The advance of the Persians into Europe failed (490 and 480–79 BC) because of the resistance of the Greeks and in particular of the Athenians. The 5th century BC saw the highest development of Greek civilization. The Classical period of Athens and its great accomplishments left a lasting impression, but the political cleavages, particularly the struggle between Athens and Sparta, increasingly reduced the political strength of the Greeks. Not until they were

conquered by the Macedonians did the Greeks attain a new importance as the cultural leaven of the Hellenistic empires of Alexander the Great and his successors. A new system of colonization spread as far as the Indus city-communities fashioned after the Greek prototype, and Greek education and language came to be of consequence in the world at large.

Greece again asserted its independence through the formation of the Achaean League, which was finally defeated by the Romans in 146 BC. The spirit of Greek civilization subsequently exercised a great influence upon Rome. Greek culture became one of the principal components of Roman imperial culture and together with it spread throughout Europe. When Christian teaching appeared in the Middle East, the Greek world of ideas exercised a decisive influence upon its spiritual evolution. From the time of the partition of the Roman Empire, leadership in the Eastern Empire fell to the Greeks. Their language became the language of the state, and its usage spread to the Balkans. The Byzantine Empire, of which Greece was the core, protected Europe against potential invaders from Anatolia until the fall of Constantinople in 1453. (The main treatment of the Byzantine Empire from about 330 to about 1453 is given in the article BYZANTINE EMPIRE, THE HISTORY OF THE.)

ROMANS

The original Mediterranean population of Italy was completely altered by repeated superimpositions of peoples of Indo-European stock. The first Indo-European migrants, who belonged to the Italic tribes, moved across the eastern Alpine passes into the plain of the Po River about 1800 BC. Later they crossed the Apennines and eventually occupied the region of Latium, which included Rome. Before 1000 BC there followed related tribes, which later divided into various groups and gradually moved to central and southern Italy. In Tuscany they were repulsed by the Etruscans, who may have come originally from Anatolia. The next to arrive were Illyrians from the Balkans, who occupied Venetia and Apulia. At the beginning of the historical period, Greek colonists arrived in Italy, and after 400 BC the Celts, who settled in the plain of the Po.

The city of Rome, increasing gradually in power and influence, created through political rule and the spread of the Latin language something like a nation out of this abundance of nationalities. In this the Romans were favoured by their kinship with the other Italic tribes. The Roman and Italic elements in Italy, moreover, were reinforced in the beginning through the founding of colonies by Rome and by other towns in Latium. The Italic element in Roman towns decreased: a process—less racial than cultural—called the Romanization of the provinces. In the 3rd century BC, central and southern Italy were dotted with Roman colonies, and the system was to be extended to ever more distant regions up to imperial times. As its dominion spread throughout Italy and covered the entire Mediterranean basin, Rome received an influx of people of the most varied origins, including eventually vast numbers from Asia and Africa.

Romanization of the provinces

The building of an enormous empire was Rome's greatest achievement. Held together by the military power of one city, in the 2nd century AD the Roman Empire extended throughout northern Africa and western Asia; in Europe it covered all the Mediterranean countries, Spain, Gaul, and southern Britain. This vast region, united under a single authority and a single political and social organization, enjoyed a long period of peaceful development. In Asia, on a narrow front, it bordered the Parthian empire, but elsewhere beyond its perimeter there were only barbarians. Rome brought to the conquered parts of Europe the civilization the Greeks had begun, to which it added its own important contributions in the form of state organization, military institutions, and law. Within the framework of the empire and under the protection of its chain of fortifications, extending uninterrupted the entire length of its frontiers (marked in Europe by the Rhine and the Danube), there began the assimilation of varying types of culture to the Hellenistic-Roman pattern. The army principally, but also Roman administration, the social order, and economic factors, encouraged Romanization. Except around the eastern Mediterranean, where Greek remained dominant, Latin became everywhere the language of commerce and eventually almost the universal language.

The empire formed an interconnected area of free trade, which was afforded a thriving existence by the *pax romana* ("Roman peace"). Products of rural districts found a market throughout the whole empire, and the advanced technical skills of the central region of the Mediterranean spread outward into the provinces. The most decisive step toward Romanization was the extension of the city system into these provinces. Rural and tribal institutions were replaced by the *civitas* form of government, according to which the elected city authority shared in the administration of the surrounding country region; and, as the old idea of the Greek city-state gained ground, a measure of local autonomy appeared. The Romanized upper classes of the provinces began supplying men to fill the higher offices of the state. Ever-larger numbers of people acquired the status of Roman citizens, until in AD 212 the emperor Caracalla bestowed it on all freeborn subjects. The institution of slavery, however, remained.

The enjoyment of equal rights by all Roman citizens did not last. The coercive measures by which alone the state could maintain itself divided the population anew into hereditary classes according to their work; and the barbarians, mainly Germanic, who were admitted into the empire in greater numbers, remained in their own tribal associations either as subjects or as allies. The state created a perfected administrative apparatus, which exercised a strongly unifying effect throughout the empire, but local self-government became less and less effective under pressure from the central authority.

The decline of the late empire was accompanied by a stagnation of spiritual forces, a paralysis of creative power, and a retrograde development in the economy. Much of the empire's work of civilization was lost in internal and external wars. Equally, barbarization began with the rise of unchecked pagan ways of life and the settlement of Germanic tribes long before the latter shattered the Western Empire and took possession of its parts. Though many features of Roman civilization disappeared, others survived in the customs of peoples in various parts of the empire. Moreover, something of the superstructure of the empire was taken over by the Germanic states, and much valuable literature was preserved in manuscript for later times.

It was under the Roman Empire that the Christian religion penetrated into Europe. By winning recognition as the religion of the state, it added a new basic factor of equality and unification to the imperial civilization and at the same time reintroduced Middle Eastern and Hellenistic elements into the West. Organized within the framework of the empire, the church became a complementary body upholding the state. Moreover, during the period of the decline of secular culture, Christianity and the church were the sole forces to arouse fresh creative strength by assimilating the civilization of the ancient world and transmitting it to the Middle Ages. At the same time, the church in the West showed reserve toward the speculative dogma of the Middle Eastern and Hellenic worlds and directed its attention more toward questions of morality and order. When the Western Empire collapsed and the use of Greek had died there, the division between East and West became still sharper. The name Romaioi remained attached to the Greeks of the Eastern Empire, while in the West the word Roman developed a new meaning in connection with the church and the bishop of Rome. Christianity and a church of a Roman character, the most enduring legacy of the ancient world, became one of the most important features in western European civilization.

The spread of Christianity

BARBARIAN MIGRATIONS AND INVASIONS

The Germans and Huns. The wanderings of the Germanic peoples, which lasted until the early Middle Ages and destroyed the Western Roman Empire, were, together with the migrations of the Slavs, formative elements of the distribution of peoples in modern Europe. The Germanic peoples originated about 1800 BC from the super-

imposition, on a population of megalithic culture on the eastern North Sea coast, of Battle-Ax people from the Corded Ware Culture of middle Germany. During the Bronze Age the Germanic peoples spread over southern Scandinavia and penetrated more deeply into Germany between the Weser and Vistula rivers. Contact with the Mediterranean through the amber trade encouraged the development from a purely peasant culture, but during the Iron Age the Germanic peoples were at first cut off from the Mediterranean by the Celts and Illyrians. Their culture declined, and an increasing population, together with worsening climatic conditions, drove them to seek new lands farther south. Thus the central European Celts and Illyrians found themselves under a growing pressure. Even before 200 BC the first Germanic tribes had reached the lower Danube, where their path was barred by the Macedonian kingdom. Driven by rising floodwaters, at the end of the 2nd century BC, migratory hordes of Cimbri, Teutoni, and Ambrones from Jutland broke through the Celtic-Illyrian zone and reached the edge of the Roman sphere of influence, appearing first in Carinthia (113 BC), then in southern France, and finally in upper Italy. With the violent attacks of the Cimbri, the Germans stepped onto the stage of history.

The nature of the Germanic migrations

These migrations were in no way nomadic; they were the gradual expansions of a land-hungry peasantry. Tribes did not always migrate en masse. Usually, because of the loose political structure, groups remained in the original homelands or settled down at points along the migration route. In the course of time, many tribes were depleted and scattered. On the other hand, different tribal groups would sometimes unite before migrating or would take up other wanderers en route. The migrations required skilled leadership, and this promoted the social and political elevation of a noble and kingly class.

In 102 BC the Teutoni were totally defeated by the Romans, who in the following year destroyed the army of the Cimbri. The Swabian tribes, however, moved steadily through central and southern Germany, and the Celts were compelled to retreat to Gaul. When the Germans under Ariovistus crossed the upper Rhine, Julius Caesar arrested their advance and initiated the Roman countermovement with his victory in the Sundgau (58 BC). Under the emperor Augustus, Roman rule was carried as far as the Rhine and the Danube. On the far side of these rivers, the Germans were pushed back only in the small area contained within the Germano-Raetian limes (fortified frontier) from about AD 70.

The pressure of population was soon evident once more among the German peoples. Tribes that had left Scandinavia earlier (Rugii, Goths, Gepidae, Vandals, Burgundians, and others) pressed on from the lower Vistula and Oder rivers (AD 150 onward). The unrest spread to other tribes, and the resulting wars between the Romans and the Marcomanni (166–180) threatened Italy itself. The successful campaigns of Marcus Aurelius resulted in the acquisition by Rome of the provinces of Marcomannia and Sarmatia, but after his death these had to be abandoned and the movement of the Germanic peoples continued. Soon the Alemanni, pushing up the Main River, reached the upper German limes.

To the east the Goths had reached the Black Sea about AD 200. Year after year Goths and others, either crossing the lower Danube or traveling by sea, penetrated into the Balkan Peninsula and Anatolia as far as Cyprus on plundering expeditions. Only with the Roman victory at Naissus (269) was their advance finally checked. Enriched with booty and constituted imperial mercenaries in return for the payment of a yearly tribute, they became a settled population. The Romans, however, surrendered Dacia beyond the Danube.

In 258 the Alemanni and the Franks broke through the lines and settled on the right bank of the Rhine, continuously infiltrating thereafter toward Gaul and Italy. Everywhere within the empire, towns were fortified, even Rome itself. Franks and Saxons ravaged the coasts of northern Gaul and Britain, and for the next three centuries incursions by Germanic peoples were the scourge of the Western Empire. Nevertheless, it was only with German help that the empire was able to survive as long as it did. The Roman army received an ever-growing number of recruits from the German tribes, which also provided settlers for the land. The Germans soon proved themselves capable of holding the highest ranks in the army. Tribute money to the tribes, pay to individual soldiers, and booty all brought wealth to the Germans, which in turn gave warrior lords the means with which to maintain large followings of retainers.

In the West, however, among the Alemanni and Franks, the beginnings of political union into larger groups did not go beyond loose associations. Only in the East did the Gothic kingdom gather many tribes under a single leadership. Above all, the development of the eastern Germans was stimulated by their undisturbed contact with the frontiers of the ancient world. Their economy, however, was still unable to support the needs of a steadily growing population, and pressure from overpopulation resulted in further incursions into the Roman Empire. The imperial reforms of Diocletian and Constantine the Great brought a period of improvement. The usurpation of the imperial title by a Frankish general in 356 let loose a storm along the length of the Rhine and subsequently on the Danube, but the frontiers were restored by the forces of the emperors Julian and Valentinian I, who repelled attacks by both the Franks and the Alemanni.

The advent of the Huns

At that time, a new force appeared. In 375 the Huns from Central Asia first attacked the Ostrogoths—an event that provoked serious disturbances among the eastern Germans. The Huns remained in the background, gradually subjugating many Germanic and other tribes. The terrified Goths and related tribes burst through the Danube frontier into the Roman Empire, and the Balkans became once again a battlefield for German armies. After the crushing defeat of the Romans at Adrianople (378), the empire was no longer in a position to drive all its enemies from its territories. Tribes that could no longer be expelled were settled within the empire as "allies" (*foederati*). They received subsidies and in return supplied troops. The Germanization of the empire progressed, that of the army being nearly completed. None of the tribes, however, that had broken into the Balkans settled there. After the division of the empire in 395, the emperors at Constantinople did all in their power to drive the Germanic tribes away from the vicinity of the capital toward the Western Empire.

From the beginning of the 5th century, the Western Empire was the scene of numerous further migrations. The Visigoths broke out of the Balkans into Italy and in 410 temporarily occupied Rome. In 406–407, Germanic and other tribes (Vandals, Alani, Suebi, and Burgundians) from Silesia and even farther east crossed the Rhine in their flight from the Huns and penetrated as far as Spain. The Vandals subsequently crossed to Africa and set up at Carthage the first independent German state on Roman soil. In the Battle of the Catalaunian Plains (451), the Roman commander Aëtius, with German support, defeated Attila, who had united his Huns with some other Germans in a vigorous westward push. The Balkans suffered a third period of terrible raids from the eastern Germans; and Jutes, Angles, and Saxons from the Jutland Peninsula crossed over to Britain. The Franks and the Alemanni finally established themselves on the far side of the Rhine, the Burgundians extended along the Rhône valley, and the Visigoths took possession of nearly all of Spain. In 476 the Germanic soldiery proclaimed Odoacer, a barbarian general, as king of Italy, and, when Odoacer deposed the emperor Romulus Augustulus at Ravenna, the empire in the West was at an end. In the East, imperial rule remained a reality, and Constantinople, also called "New Rome," survived many sieges until its fall in 1453. In comparison, "Old Rome" declined into an episcopal centre, losing many of its imperial characteristics.

(H.Au./Ed.)

The reconfiguration of the empire. By the end of the 5th century, however, most of the non-Roman peoples settled in the West were adopting Roman customs and Christian belief. Intermarriage with established Roman families, the assumption of imperial titles, and, finally,


OSTROGOTHS
VISIGOTHS
VANDALS
HUNS
SCOTS, PICTS
ANGLES, SAXONS, JUTES
Route of the Goths
Route of the Visigoths
Route of the Vandals
Route of Attila
Route of Scots, Picts
Route of Angles, Saxons, Jutes
Trade routes Constantinople/Scandinavia
SCANDINAVIANS
Vineland (America) 1000.
Greenland 986, Iceland 874.
Faeroe and Shetland islands c. 700
PICTS
SCOTS
SCANDINAVIANS 830
BRITONS
ANGLES
DANES 780–850
9th century
SCANDINAVIANS
SAXONS
JUTES
NORTH SEA
SCANDINAVIANS
GOTHS
BALTIC SEA
Niemen
Lake Peipus
Novgorod
SCANDINAVIANS
ATLANTIC OCEAN
LOMBARDS
SAXONS
FRANKS
Dorestad
Cologne
THURINGIANS
Trier
Mainz
Metz
Seine
Meuse
Moselle
Rhine
Rhône
Loire
Somme
Marne
Yonne
Saône
Aisne
BRITONS
BRITONS
Orléans
Troyes
Chalons
BURGUNDIANS
Strasbourg
ALEMANNI
Tours
FRANKS 486–493
BURGUNDIANS 443
Lyon
ALPS
SUEBI 411
Leon
Tolosa
Paris
Artes
Pollentia
Milan
Ravenna
Rome
Capua
Aquileia
LOMBARDS 568
AVARS 567–796
Sirmium
Singidunum
Danube
RUGIANS
GOTHS
BURGUNDIANS
VANDALS
SUEBI
Vistula
Oder
Elbe
Weser
Main
Rhine
Meuse
Seine
Loire
Somme
Marne
Yonne
Saône
Aisne
Moselle
Rhine
Rhône

The Middle Ages

The term middle age (*medium aevum*) was first used in the late 15th century by humanist scholars as a description of that period of western European history between the collapse of Roman civilization in the 5th century AD and the revival of civilized life and learning in which the humanists believed themselves to be participating. Those centuries saw the emergence of Europe as a cultural unit and the rise and decay of a distinctive civilization within it.

The materials from which this civilization was molded were essentially threefold: the inheritance of classical antiquity, Christian tradition, and Germanic and Scandinavian social patterns. Classical antiquity, which set the standards of learning, culture, and government by which medieval no less than Renaissance scholars measured their own achievements, passed into Europe by several routes. Over part of Europe, most notably Italy, Spain, and southern France, the Germanic invaders entered a society in which Roman social and political organization, urban life, and even local government continued—much enfeebled, but never totally interrupted. In northern Gaul, always more thinly Romanized, this was much less true; in Britain, little but the roads and crumbling walls survived as witness to the secular presence of the empire. The Roman Catholic church was able to play an essential role in preserving literacy and even some classical learning in its liturgy and literature, in maintaining some of the forms of public administration in its diocesan government, in perpetuating the tradition of corporate responsibility for peace and the relief of want, and perhaps most of all in creating a new universal society to replace that once provided by the fallen empire. It was ultimately the Latin church rather than the Roman imperial tradition that determined the frontiers of modern Europe. (Ma.Br.)

EARLY MIDDLE AGES

Between the 5th and 8th centuries AD, the early Middle Ages, the imperial government of Europe was replaced by separate Germanic tribal states imbued by Christian faith. This transformation was accompanied by the rapid spread of Christianity, which gradually established a cultural and linguistic unity throughout Europe. In this way, paradoxically, the ancient pagan capital of Rome became the chief Christian centre, as the see founded by St. Peter, to whom Christians everywhere were devoted. But it was now deprived of significant political or military authority, which meant that successive bishops of Rome regularly called upon other Christians for protection. The failure of the Eastern Roman Empire to respond to these appeals marked its isolation from the West.

The early history of medieval Europe is dominated by the alliance between the pope (*papa; i.e.,* "father" of Rome) and the descendants of Clovis I, king of the Franks. This alliance was sealed by the coronation of Charlemagne by Pope Leo III on Christmas Day, 800. It also represented a revival of some of the imperial traditions of ancient Rome, in turn transformed by Christian faith. The Holy Roman Empire of the West, in contrast to the Eastern Roman Empire of Constantinople, thus became a lasting ideal in Christian Europe.

Toward a unified Christian religion. *Varieties of Christianity.* To account for this process of Christianization, it is necessary to survey the forces working to extend and deepen the faith in Europe. In the late 5th century, when non-Roman forces effectively took over the Roman Empire, several forms of Christian authority were known: the urban hierarchy of bishops, established in or near the major cities and ranked according to geographic diocese; monastic communities, dedicated to spiritual perfection; and isolated holy men unattached to other groups. The faith was represented by a variety of monuments, ranging from cathedral churches, some with magnificent decoration, to isolated rural shrines, often containing the relics of martyrs and saints reputed to work miracles. Overall, the character of each Christian region differed according to the history and method of its evangelization.

Perhaps the most effective episcopacy was based in the highly developed cities of Italy, though Ostrogothic clergy imposed Arian beliefs in some of them. Along the coasts and on isolated islands, monastic communities represented the ascetic traditions of the Desert Fathers. In Gaul, St. Martin combined this monastic training with episcopal office, though he refused to wear the bishop of Tours' official costume. After his death, his relics made his shrine a major centre of pilgrimage. Elsewhere the local Gallo-Roman aristocracy provided many well-trained bishops, such as Sidonius of Clermont, who grafted Christian learning onto traditional Roman education. In Ireland, St. Patrick had less lasting success in setting up an episcopal organization, which never took strong hold. Although these churches were united in their respect for St. Peter's foundation at Rome, each pursued its own separate trajectory.

Christian monks also participated in the process of evangelization. The appeal of monasteries such as Lérins in Provence, often founded on Pachomian (cenobitic) models, was heightened by the wide circulation of histories of saints and martyrs, particularly the 4th-century *Life of St. Antony* attributed to Athanasius. Such tales inspired individuals to practice asceticism, visit the Holy Land, and dedicate their family wealth to the church. Other associations existed in the form of family foundations, house monasteries, and groups of dedicated women, such as the one for whom Egeria (Etheria) wrote her pilgrim diary, the late 4th-century *Peregrinatio Etheriae.*

Paganism was only one of the forces hostile to the expansion of Christianity. Intense opposition to official belief derived from heretical movements, in turn condemned by ecumenical and local councils and by emperors. The most widespread of these was Arianism, which denied the divinity of Christ. Traces of Pelagianism (which denied the concept of original sin and emphasized free will) and Priscillianism (a dualistic doctrine denying the humanity of Christ) continued to inspire wrong beliefs, and, in remote areas where Christianity was little known, the worship of the old gods was sometimes combined with Christian practice in a syncretic attempt to ensure protection. Heretical movements

In this profoundly non-Christian Europe, the major achievements of the 6th century were the establishment of Western monasticism, the conversion of the Arians and pagans to orthodox Christianity, and the elaboration of methods of sustaining correct Christian belief.

The growth of Western monasticism. Although many monasteries had been set up in the West before the 6th century, that founded by St. Benedict of Nursia (*c.* 480–*c.* 547) established new methods for the organization of religious communities, which proved immensely influential. Benedict's Rule provided celibate Christians with a clear daily timetable of prayer, manual work, and study. At Monte Cassino in central Italy monastic self-sufficiency was wedded to Christian devotion, as spiritual training was combined with agricultural activity. This routine represented a less stringent asceticism than Celtic traditions and offered less intellectual stimulus than did more scholarly foundations. But, in its simplicity and moderation, the Rule of St. Benedict proved a most effective medium for spreading celibate asceticism.

In the 580s the monastery of Monte Cassino was attacked by Lombard forces, and its precious copy of the Rule had to be carried to safety in Rome. Although the community was later refounded, the attack emphasizes the fragility of early medieval monastic institutions. In southern Italy, Cassiodorus established his own monastery of Vivarium with an unusually rich library and scriptorium; he wrote a guide, the *Institutes,* for monastic scribes and copyists. But after his death the community could not sustain his high aims, and his collection of books was dispersed. Similarly, many older monasteries did not endure into the medieval period.

On the remote northwestern coasts of Ireland and Scotland, a highly ascetic monasticism had developed, directly inspired by Egyptian holy men. These monks lived in individual cells, observing a strict penitential discipline, and displayed a missionary zeal that effectively replaced St. Patrick's episcopal church during the 6th century. By developing links with local magnates, they sought to secure secular protection. When St. Columba founded a community on Iona in 563, he intended not only to con-

vert the Picts but also to secure his own princely position against rivals in Ulster. When St. Columban set out from Ireland with a group of companions to evangelize Europe, he actively sought lay patronage and protection for his remote foundations at Luxeuil in Burgundy and Bobbio in the Apennines.

Some conflict between Celtic and Benedictine monasticism was probably inevitable. In the early 7th century, it was fought out in Columban's quarrel with Pope Gregory I over the correct method of calculating the date of Easter, rather than in disagreement over monastic organization. But, in the long run, the Rule of St. Benedict proved a more accessible and practical guide for European monasticism than the less routine and more stringent Celtic traditions. Nonetheless, many Celtic communities flourished, and the foundation of Columban's disciple Gall in the Alps survives to this day, identified (as Sankt Gallen, or Saint-Gall) only by its founder's name. And the fact that both approaches could coexist reflects the strongly felt need for Christian ascetic practices in early medieval Europe.

The conversion of non-Roman leaders. In this matter, the attitude of the military leader, normally the king, was decisive, so bishops and monks usually directed their efforts toward the ruler. If he or his wife could be persuaded to abandon the ancient beliefs, the chiefs and magnates would often follow suit.

Among the Germanic tribes established in the West in the early 6th century, the Franks clung to their pagan beliefs and did not adopt Arianism. To win over Clovis, their leader since 481, Bishop Remigius of Rheims indicated that he would bring the young king ecclesiastical support and legitimation if he would convert. Remigius was assisted by Clovis' wife, Clotilda, who was an orthodox Burgundian Christian. Finally, after an important victory over the rival Alemanni, Clovis agreed, and, at the turn of the 5th/6th century, he was baptized by the bishop (the actual date is disputed). His son and heir and allegedly 3,000 men of his army adopted Christianity in a mass ceremony.

The conversion of Clovis

By his conversion Clovis won the support of many influential Gallo-Roman families as well as bishops, and he advanced south against the Arian Visigoths, who were established around Toulouse. At the battle of Vouillé in 507 the Visigoths were defeated and their king Alaric II was killed. Frankish and Christian control was thus extended far to the south, while the Visigoths retreated over the Pyrenees to Spain. The following year, Clovis received the honorary title of consul from the Eastern emperor, Anastasius I, and entered Tours wearing a purple tunic and scattering gold to the crowd, who acclaimed him consul or emperor. In the last year of his life (511), Clovis summoned his bishops to a council at Orléans and directed the proceedings. The Franks thus forged a close relationship with Gallo-Roman scholars who had entered the church in Gaul and acquired from them some classical learning and legal expertise. The Germanic principle of partible inheritance, however, meant that Clovis' sons divided his kingdom and continually fought each other to extend their own regions.

At the end of the century, another momentous conversion occurred. When Pope Gregory I the Great (590–605) heard about the northern Anglo-Saxons, who had introduced their own gods to the British Isles and driven the indigenous Celtic Christians into distant western regions, he sent a high-powered missionary team to convert them. Led by Augustine, the prior of a Benedictine monastery in Rome who became the first archbishop of Canterbury, they succeeded in baptizing King Aethelberht of Kent with the assistance of his Frankish wife, Bertha. The subsequent establishment of Christian institutions according to Gregory's organization combined an effective episcopal church with monastic training, but it provoked hostility among the Celts.

The conversion of the Anglo-Saxons must owe something to Gregory's detailed instructions, which accompanied his second mission, sent in 601. In these letters addressed to its leader, Abbot Mellitus, the pope answered Augustine's questions about the conversion process. He dealt with troublesome issues, such as prohibited degrees of marriage, and the most basic problems of paganism, particularly what should be done with the pagan temples and their idols and shrines. From the original order to destroy them, Gregory changed his mind and recommended that these sites should be transformed into churches and reconsecrated for Christian use with nearby houses where feasts could be held. Of course, idols had to be removed, but places sacred to pagans could be reemployed by Christians.

Hirmer Verlag, Munich



Original colonnade of the cathedral at Syracuse, Italy, built c. 480–460 BC as a temple of Athena. The temple was converted into a cathedral in the 7th century AD.

Despite papal sanction for such careful procedures, the Celtic Christians, in particular the Welsh monastery of Bangor, refused to recognize Augustine's authority. This clash, in 603, prefigured later ones and drew up the battle lines of monastic versus episcopal churches. But the bishops, monasteries, and schools established at Canterbury, Rochester, London, and York laid the basis for a particular loyalty to the church of Rome among the Anglo-Saxons.

A similar procedure of conversion was employed in many areas of the West, where the Goths had established their own Arian bishops; in others, such as Ravenna, they disputed control with an orthodox clergy. Again, orthodox bishops found it best to try to convert particular rulers rather than their clergy. In Burgundy, Avitus of Vienne won over King Gundobad; among the Sueves, it was Martin of Braga; and, in Visigothic Spain, Leander of Seville. Thus the Burgundians (517), Sueves (561), and Visigoths (589) were finally won to orthodoxy.

The conversion of the Arians

Methods of sustaining correct Christian doctrine. In the wake of mass conversions from both Arianism and paganism, the churches of the West tried to develop ways of preserving the correct faith. Instructions were drawn up, often in question-and-answer form (for instance, by Martin of Braga), and collections of sermons by celebrated bishops, such as Caesarius of Arles, were made to assist bishops. (Christian learning was often transmitted in collections of excerpts, called florilegia—"gatherings of flowers.") In Spain, King Recared insisted that the creed should be recited during the liturgy so that everyone would learn it correctly, a novelty in the West. This initiative was accompanied by a change in the wording of the creed to reflect the belief that the Holy Spirit proceeds from

the Father and the Son. As St. Augustine had sanctioned this additional clause, *Filioque* ("and from the Son"), the Spanish bishops relied on the highest Western authority. Even this, however, did not guarantee acceptance of their form of the creed.

While the circulation of model sermons and question-and-answer texts provided bishops with material, Pope Gregory I gave attention to the fundamental problem of training bishops. His *Book of Pastoral Care* (*Regulae pastoralis liber*), addressed to John of Ravenna, instructs bishops as to their duties, their dignity, and their need for the monastic virtues of humility, chastity, and obedience. Gregory urged his bishops to set an example of Christian living that would influence others. The text shows how intimately monastic and episcopal training was linked in his mind. A similar concern about Christian standards is evident in Gregory's attitude toward ancient learning, which was to be subordinated and harnessed to Christian belief, not pursued for its classical content. Only then could its pagan origin be rendered safe for Christians.

The 7th century. *The Franks, Visigoths, and Anglo-Saxons.* In the Frankish state set up by Clovis, his descendants continued to feud among themselves and against local rivals. Gradually, the northern regions of Neustria and Austrasia and, farther south, Aquitaine became identifiable kingdoms ruled by separate members of the Merovingian dynasty (named after the 5th-century leader Merovech). But only rarely did one ruler, such as Dagobert I (629–639), unite these areas under his personal rule and defend them against Avar attacks from the east.

Amid these disturbed conditions, while both episcopal and monastic leaders exercised spiritual authority, power was vested in the magnates with armed retainers, who could rival nominal Merovingian kings. It was from one of these families—the Arnulfings, established in the Ardennes—that a significantly stronger leader would eventually emerge. The process extended from Dagobert's death through three generations, as the Arnulfings secured their control over Austrasia by monopolizing the role of mayor of the palace. In 687 Pepin II defeated the Neustrians and established his authority in the north, fighting off Burgundian, Franconian, and Frisian attacks. Throughout, Merovingian kings ruled but became in fact less and less effective. This imbalance in real power set the stage for Pepin's grandson to argue that, as effective ruler, he should also be king.

A rather different development prevailed among the Visigoths, who established a strong monarchy in Spain. Unlike all the other Germanic tribes, they managed to sustain a centralized kingdom, with a capital at Toledo and an efficient administration. In this the Visigoths were aided by an exceptionally powerful church, run by highly educated bishops such as Isidore of Seville, who also patronized monastic foundations. The Christian monarchy of Spain assumed the Eastern tradition of summoning and presiding at councils that legislated for the entire country; it also persecuted the Jews.

Anglo-Saxon Christianity

Among the Anglo-Saxons, conflicts between Roman and Celtic forms of Christian worship continued to weaken the northern kingdoms. The vitality of Irish and Scottish monasticism, clear from the foundation of Lindisfarne in 635, exacerbated tensions that were only resolved at Whitby in 664. At this synod the Celtic party, led by Colman, was worsted in the argument about the dating of Easter, and King Oswiu of Northumbria adopted the Roman system. From this time onward, England benefited increasingly from closer relations with Christian Europe. Monastic and regal pilgrims to Rome deepened the devotion to St. Peter and persuaded Pope Vitalian in 668 to send a further missionary effort to England. St. Benedict Biscop, an indefatigable pilgrim and founder of the monastery of St. Peter at Wearmouth, accompanied Theodore of Tarsus back to Canterbury, where he revived the traditions established by Augustine. Subsequently, Roman building styles, chant, vestments, icons, and liturgical books enhanced local Christian traditions in England. They contributed to the flourishing Anglo-Saxon culture documented in the writings of the Venerable Bede, a monk of Wearmouth, whose intellectual curiosity and scholarly achievements were exceptional. His *Ecclesiastical History of the English People* inspired later generations of scholars, including Alcuin, and made York a centre of learning.

Throughout the 7th century, increasing Roman influence north of the Alps was counterbalanced by an ever more precarious military situation in the city of St. Peter. The Lombards pressed southward, determined to capture Rome, while the protection promised by the exarch of Ravenna proved singularly ineffective. In addition, Pope Honorius I was drawn into the Eastern debate over the wills and energies of Christ that provoked a schism between Rome and Constantinople. From the middle of the century, however, a series of able popes, elected largely from Greek-speaking communities, provided skillful diplomatic leadership.

Under Agatho (678–681), Emperor Constantine IV expressed the desire to end the schism by an ecumenical council, and the pope made careful preparations for the Western churches to be properly represented. He obtained the support of ecclesiastical leaders from England, Spain, and probably other regions for the condemnation of monotheletism (the theory of Christ's one will) before dispatching an impressive team to the East. At the sixth ecumenical council, in Constantinople (680–681), these Western representatives were accorded seating precedence and signed the acts first. The resumption of ecclesiastical unity did not greatly increase communication between East and West, but it enhanced Roman claims to represent the Latin-speaking churches of the West within the much larger medieval Christian world.

The rise of Islām. This sense of Christian identity was particularly important because Europe was about to be challenged by a new monotheistic religion, armed with ferocious military power, in the form of the Muslim faith. The rise of Islām is much debated. Because the sources that describe its origins date from centuries later, it is especially difficult to account for the rapidity of Islāmic conquest. However, during the 630s and 640s, the followers of the Prophet Muḥammad advanced from Arabia, captured large areas of the Eastern Roman Empire, and destroyed the ancient empire of Persia. By 680 the Arabs had mastered naval skills, occupied Cyprus and Rhodes, and besieged Constantinople. Their impact in the East was soon to be repeated in the West, as they marched across North Africa, capturing Carthage (698) and crossing over into Spain (711).

At the turn of the 7th/8th century, therefore, Europe was faced by a completely novel invader from the south, while its internal conflicts were by no means resolved. The Visigothic kingdom collapsed without a struggle, and only in the northwestern corner of Galicia did an independent church survive. Under Islāmic toleration, however, the Mozarabic Christians and Jews continued to develop their own faiths. Some of the Visigothic achievement was sustained to inspire later generations.

The 8th century. *The formation of the Carolingian dynasty.* Given the speed with which Islām had overrun vast imperial territories in the East, it is quite surprising that the Arabs did not succeed in occupying more of Europe. The fact that they were checked at the natural frontier of the Pyrenees is largely due to an untypical cooperation between rulers in Aquitaine and Austrasia. Under Charles, the illegitimate son of Pepin II, mayor of the palace, a united force defeated the Arabs at a battle traditionally dated to 732 and located at Poitiers. (In fact, it probably occurred near Tours in 733.) This victory endowed Charles with his nickname, Martel ("the Hammer").

Charles Martel

Although, like his father and grandfather, he held the title of mayor of the palace, Charles was king of Austrasia in all but name, and, after the death of the Merovingian ruler Theodoric (Theuderic) IV in 737, he simply took over. For many years he had protected Anglo-Saxon monks, such as Boniface, who had devoted their energies to converting the pagan Saxons in the East. This had brought him to the notice of Pope Gregory III (731–741), who also supported the missionaries. In 739 Gregory wrote asking Charles as subregulus (under-king) to come and defend Rome against the Lombards. Although the appeal was not successful, Charles did return the papal embassy.

In contrast, the Eastern emperor, Leo III (715–741) not only refused to fight the Lombards but also supported the heretical practice of iconoclasm (destruction of religious images) and removed ecclesiastical property in southern Italy to Constantinopolitan control. From 731 to 786 this provoked another schism between East and West.

Charles Martel divided his territories between his two sons, Carloman and Pepin, but they agreed to restore King Childeric III, who was brought out of a monastery. When Carloman retired from the world to become a monk at Monte Cassino in 747, his brother Pepin assumed full power. Under these new circumstances, the Austrasian mayor inquired of Pope Zacharias (741–752) if it was right for the man who had no power to govern the kingdom to be called king. With papal approval, Childeric and his son were sent into a monastic exile. Pepin was elected by the nobles, anointed by the bishops, and enthroned as King Pepin III in 751. The Carolingians (so called from Carolus, or Charles) had finally replaced the Merovingians.

The Franco-papal alliance and creation of the Holy Roman Empire. Pepin was almost immediately called upon by Rome, for in the same year Ravenna fell definitively to the Lombard king, Aistulf, marking the end of the Byzantine exarchate. Pope Stephen II (752–757) thought that only drastic action could save the city, and he set off to cross the Alps—the first time a bishop of Rome had journeyed to northern Europe—to make a personal appeal to Pepin. At the royal palace of Ponthion, an alliance was sealed in 754. This final resolution of the early medieval papacy's problem of secular protection was tested in Pepin's Italian campaigns of 755 and 756. Carolingian military forces defeated Aistulf and freed Rome of Lombard pressure for the first time in centuries.

The alliance was further deepened by a spiritual bond of *compaternitas* (co-paternity) that made bishops of Rome godfathers of royal Carolingian infants. Franco-papal friendship thus became the most significant alliance in the West and influenced later political developments. Enhanced by his role as protector of the bishop of Rome, Pepin proceeded to support reform of Frankish religious institutions under the guidance of Chrodegang, bishop of Metz. He also revised the Lex Salica in 763–764, adding a prologue that reflects pride in the Franks, a most Christian people. At his death in 768, however, his two sons, Charles and Carloman, inherited rather unequal shares in the kingdom.

Charlemagne: "the father of Europe"

Charles, later identified as Charlemagne ("Charles the Great"), took advantage of his brother's death in 771 to unite the Carolingian territories, to which he added many conquests, notably Saxony, Aquitaine, and Septimania. He again campaigned on behalf of Rome and secured the return of territories in central Italy to the see of St. Peter. During his long reign, the core of western Europe for the first time had one ruler, a fact that recalled the universal rule claimed by ancient emperors. Many other factors—including his concern for administration, justice, education, founding of a capital city at Aachen, and patronage of the arts—led contemporaries to compare him with Roman rulers. He also was identified by Alcuin as "the father of Europe," a title that brought the term Europe into common use. So the action of Pope Leo III in crowning Charles as Holy Roman emperor was quite apposite, if apparently unwelcome to the king.

The creation of an emperor in the West, however, raised problems in the East, where Empress Irene (797–802) had restored the veneration of icons and ruled in place of her son, Constantine VI. At Constantinople, emperors considered themselves the sole legitimate heirs of ancient Rome. Charles' imperial title was to prove a stumbling block in all subsequent East-West relations, but the papal coronation created a lasting ideal in the West, pursued by rulers for centuries.

At the beginning of the 9th century, western Europe appeared strong. Politically united under Charlemagne, spiritually directed by the bishop of Rome, with a flourishing and varied monastic culture stretching from Scotland to Sicily, the intellectuals of the Carolingian Renaissance manifested vitality and confidence. These strengths were essential for Europe to combat the Scandinavian Vikings, the eastern Bulgars, and Arab pirates, whose devastating raids would set back European development for many years. Yet the Vikings would be driven off, the Bulgars would eventually be converted and absorbed by Byzantium like so many other invaders, while Arab control of the Mediterranean would prove limited. In this process the long reign of Charlemagne proved crucial, for it permitted the growth of medieval European identity and culture. And this in turn fostered the development of feudal ties and economic development that characterize the later Middle Ages. (J.E.He.)

MEDIEVAL SOCIETY

For most of the medieval period in most of Europe, the structure of society was determined by the difficulties of providing an adequate and continuous supply of food and raw materials. The proportion of grain reaped to seed sown was generally low; acute difficulties of transport made agricultural specialization hazardous and prices local and unstable. Hence, particularly between the 8th and 11th centuries, the proportion of the population freed of all agricultural tasks was low, and the materials of luxury or warfare were rare and highly prized.

The aristocracy that could be supported by such a society was both in form and origin a blend of Roman and Germanic elements. Late Roman society was marked by the existence of an aristocracy of wealthy landowners whose estates were worked by slaves either maintained in the household or housed on small plots about the great house. Other dependents, of rather higher status, might be freedmen or formerly independent cultivators, such as the coloni, whom war or financial distress had brought under the landowner's protection. Well before the formal end of the empire in the West, such landowners had been accustomed to deal out a usurped justice even over their free clients and had maintained armies of *bucellarii* (bodyguards) in their own defense, though rarely placing a high value on military accomplishments. With difficulty they retained their contacts with the towns and with the traditional urban education of their class.

Decline of the economy

Earlier Roman government had depended upon these towns, which were almost universally in decline by the 5th century. Vandal and, later, Muslim piracy disrupted the vital sea routes to Africa and the East; on land the impotence of local government made communications dangerous; and ever-heavier taxation crippled trade. Long-range commerce and the more local urban industries declined, until even wheel-turned pottery became scarce or vanished. The retreat toward economic self-sufficiency and a barter economy was reflected in the near collapse of Western coinage. Over this society, rapidly retreating into a pre-Roman localism, there presided, with ever-feebler effect, an emperor or emperors who attained office at the head of an army and according to no settled principle of succession. Once in power, the emperor exercised an absolute authority over the army, the courts, and the administration, limited only by prudence and the likelihood of mutiny or assassination. Emperors were hailed as divine before the conversion of Constantine early in the 4th century; thereafter, even a Christian emperor who enforced the precepts of the church readily took on a quasi-priestly character.

The Germanic invaders who settled in or along the frontiers of this empire lived very differently. Not all seem to have had kings, at least permanently, but the majority, whether as allies or invaders, entered the empire as warrior bands led by chiefs who depended for power on their continued capacity to win battles and to retain followers with gifts of present wealth and hope of more. Kings were ring givers, holders of great feasts, lords of men. Yet their authority rested on other grounds too—their descent from the gods and a belief sometimes current that divine favour was assured the people through the royal lineage. Some of the pagan kings (such as the Ynglings of Sweden) acted as priests, and a king's subjects usually followed him to the font for baptism as they followed him to war. Very special measures, including the earliest recorded Frankish consecration by a bishop, were required to legitimize the succession of a king from outside the ruling dynasty.

The politically active element in the people was represented by the warriors—the freemen—who formed the army; when this was gathered, it represented the people for war or peace, and it was the army that acclaimed each new king by raising him upon their shields or enthroning him upon some sacred stone. Among these freemen there was a group of special importance and standing, set apart by their birth and their lord's favour—the comitatus, or *gasindi*, already known to the Roman historian Tacitus in the 1st century AD. For them, loyalty to their lord was the supreme virtue, celebrated in epic verse from *Beowulf* on. From their ranks were drawn the barbarian officers of post-Roman and Germanic society, though the highest such posts seem to have been monopolized by a restricted number of noble kin groups, distinguished by their descent and deeds rather than by any set title to property.

The rulers. *Emperors.* The last emperor of the West in direct succession to Augustus was Romulus Augustulus, a shadowy figure deposed in 476. On Christmas Day, 800, a new empire began with the coronation of Charlemagne by Pope Leo III in Rome. Even geographically, this empire was very unlike that of antiquity. The first empire had grown out from the city of Rome to embrace the entire Mediterranean coastline, with varying amounts of the hinterland. In the realm of Charlemagne, Rome was a frontier city, at the southern limit of an empire that extended from the Atlantic to the Elbe and from the border with the Danes into central Italy. The centre of Charlemagne's empire lay at his palace at Aachen (outside the limits of the old empire) rather than in Rome. Of his successors, only Otto III (983–1002) spent any length of time in Rome. Charlemagne was incomparably the most powerful Christian king of the West, but even he enjoyed no formal authority over other kings, before or after 800. Although the title remained in his family (the Carolingians), the lands were often divided up among its members.

The imperial coronation of Otto I, king of the East Franks, in 962 marked a further change. Otto enjoyed political power little less than that of Charlemagne but had no claim to direct authority among the West Franks. From his reign onward, the imperial title became the prerogative of the kings of Germany, though one they could only enjoy once crowned by the pope.

Ecclesiastical and secular roles

The content of the imperial office was always confused and uncertain. It could be considered a recognition of facts—the attribution of a supreme title to the most powerful of the Latin kings—and many saw Charlemagne or Otto I in this light; but none of their successors enjoyed the same authority as did these founders of empire. The more general view, dominant by the end of the 10th century, was that the empire was specifically Roman, but in several possible senses. Because it was Pope Leo III who had recognized Charlemagne as the first emperor in the West in 300 years and because Leo's successors had the undoubted right to consecrate later emperors at Rome, it could be claimed that the empire was an office within the Christian community, or ecclesia. The chief duty of the emperor would then be the protection of the church and the enforcement of ecclesiastical discipline. When Henry III summoned the synod of Sutri of 1046, which ratified the withdrawal of three rival popes, he fulfilled one interpretation of this role; when Pope Gregory VII declared Henry IV deprived of his kingship in Italy and Germany for offenses against the church in 1076, he was employing another. After the Investiture Controversy between the papacy and the Salian kings of Germany, and its resolution at the Concordat of Worms in 1122, the extent of imperial claims to authority over the church was considerably reduced, at least in theory.

However, Rome had been the city of the Caesars as well as of St. Peter, and some claimed that the emperors were the heirs of Augustus and the pagan emperors as well as of Charlemagne, with a universal authority that owed nothing to the church. This view was asserted notably by the apologists of Frederick I Barbarossa (1152–90), supporting their claims upon the revived study of the Roman civil law; modified by the doctrines of Aristotle, it survived in the writings of Dante and among the courtiers of the emperor Henry VII (1308–13).

Without effective control in Rome, any version of these views lacked substance. From the beginning of the 9th to the end of the 12th century, the emperors enjoyed substantial rights, and even larger claims, in Lombardy, Tuscany, and central Italy. Imperial control in Lombardy, particularly over the church, was often effective until the Investiture Controversy, and by no means negligible after that. The defeat of Frederick Barbarossa by a league of Lombard towns at Legnano in 1176, the papacy's determination to establish an independent state in central Italy under Innocent III and his successors, and the consequent wars with Frederick II (1220–50) saw the imperial rights in Italy dwindle toward insignificance. After the death of Frederick II, who had united the crowns of Germany, Italy, and Sicily in his own person, prolonged succession disputes on both sides of the Alps ruined the foundations of central authority in northern Italy and Germany. By the time of the last imperial coronation in Rome, that of Frederick III in 1452, the universal and ecclesiastical pretensions enshrined in the ceremony had long been a fiction. Frederick was to spend the bulk of his reign (1440–93) trying to maintain a foothold even in his own duchy of Austria. For much of the period between 800 and 1500, the empire is best considered as only the most prestigious, and often not even the strongest, among the kingdoms of the Latin West.

Kings. The immediate successors of the old empire were a number of unstable kingdoms. Their origins lay in the widespread movement of peoples from Asia westward, which had threatened the empire from the 3rd century. In the course of the 5th century, the defenses of the empire collapsed. In 410 an army of Visigoths, first discernible on the northern shores of the Black Sea, sacked Rome itself under their leader Alaric. In the course of the next century, they moved north and then west to establish a Visigothic kingdom on either side of the Pyrenees. Though under attack from the Franks, they maintained themselves in Spain until the Muslim invasion of 711. The Vandals under Gaiseric invaded North Africa in 429 and established a short-lived kingdom there until it was destroyed by Belisarius, the general of the eastern emperor Justinian, in 533. The Burgundian kingdom on the Rhône and the Ostrogothic kingdom of Italy, founded by Theodoric, lasted little longer. The armies that created these kingdoms were relatively small and usually of mixed composition; there was no very sharp break in the life of the provinces they settled. There were serious religious difficulties with the Roman population, since the new rulers were all formally followers of the Arian heresy. Roman Catholics were liable to occasional persecution and much discrimination, at least until the conversion of the Visigothic king Recared in 589. Nevertheless, an outstanding means for the transmission of the learning of antiquity was to be found in the writings of Cassiodorus and Boethius in Ostrogothic Italy and Isidore of Seville under the Visigoths.

The more enduring kingdoms were established by the Franks on either side of the lower Rhine; by smaller groups of settlers, imperfectly defined as Saxons and Angles, in Britain; and by the Lombards in northern Italy.

The Lombard kingdom, established by degrees at the end of the 6th century over modern Lombardy with semi-independent duchies at Spoleto and Benevento farther south, survived as a loose-knit entity until the defeat of its last king, Desiderius, by Charlemagne in 774. The kingdom of Lombardy, with its capital at Pavia, retained much of its distinctive character, but as a part of the Frankish empire.

The Anglo-Saxon petty kingdoms, notably in Northumbria, Mercia, Wessex, and Kent, were established by the beginning of the 7th century, and hegemony was disputed between them until the 9th century invasions of the Danes destroyed all but Wessex, which held out under King Alfred (871–899). Under his successors, a united kingdom of the English was created by the reconquest of the lands taken by the Danes, a process completed under King Eadred in 954.

By far the most important of the successor kingdoms, however, was that of the Franks. Unlike the other Germanic peoples, the Franks expanded from their earlier territory without abandoning it and had only the briefest

of flirtations with Arian heresy. North of the Loire they were a numerous people, and throughout their realm assimilation with the earlier Gallo-Roman population seems to have been relatively easy and complete.

The empire of Charlemagne broke up soon after his death. Its great extent left it vulnerable to a new wave of attacks from the Vikings of the north and the Magyars from the east. Even so, it was to exercise incalculable influence on the later history of Europe. The later shape of the political map was determined partly by the pattern of the disintegration of the empire and partly by the creation of new kingdoms along its periphery.

In the 10th century, the eastern and western halves of the empire parted decisively. In the east Louis IV, the last Carolingian king, died in 911. The Saxon kings from Henry I (919–936) onward reestablished royal authority among the East Franks, attached the "middle kingdom" of Lotharingia (Lorraine) to their crown, beat off the last great assault of the Magyars at the Battle of the Lechfeld in 955, extended their lands east of the Elbe, and after 951 claimed the crown of Lombardy as well. In the west the Carolingian line lingered on until the death of Louis V in 987. He was succeeded by the greatest of his subjects, Hugh Capet, whose descendants in the direct line ruled France until 1328.

Over succeeding centuries, the boundaries of Christian Europe expanded, by both conquest and assimilation. The reconquest of Muslim Spain, beginning in the mid-11th century and completed with the capture of Granada in 1492, saw the rise of the kingdoms of Navarre, Leon, Castile, Aragon, and Portugal. To the north, the three distinct kingdoms of Denmark, Norway, and Sweden had acquired a measure of internal unity and external independence by the mid-11th century, when the rulers of all three were formally Christian. To the east, Poland (by 1076), Hungary (999), and Bohemia (1085) were recognized as independent kingdoms by the emperors and the church (though Bohemia remained a fief of the empire). In southern Italy, Norman adventurers carved out new lordships at the expense of the Muslims of Sicily and the Lombard and Byzantine rulers of Apulia and Calabria; united under Duke Roger II, these were formally acknowledged as a kingdom by 1139. The Crusades created a series of similar, though short-lived, kingdoms in the eastern Mediterranean and a more enduring lordship in the lands of the Teutonic Knights along the shores of the Baltic.

The elements from which these kingdoms were created varied widely, but some general properties can be discerned. Most medieval kings were raised to office by a combination of ritual acts that revealed the origins of their power. Until the principle of primogeniture became dominant in the late 12th century, the king would first be "chosen" in an assembly from among the kin of the last ruler, whose designation would carry great weight in cases of doubt; this choice was often not complete until the new king had traveled through his kingdom in what has been called a continuous election. After the consecration of Pepin III the Short, it became increasingly common for the king to be consecrated with a liturgy carefully modeled upon the Old Testament precedents of Saul and Solomon and to be invested with such insignia as crown, sword, helmet, or sceptre. Before or after this ceremony, the leading men of the kingdom came to declare their allegiance, often performing symbolic acts of domestic service at the coronation feast. In these ceremonies, the king secured both rights and duties. As the anointed of the Lord, he had a special claim on the obedience of the church and a measure of physical security; the murder of King Canute II of Denmark in 1086 was widely reckoned a martyrdom, and the violent deaths of kings continued to be regarded as striking at the fabric of the divine and human order. This process, whereby the church sharply distinguished the king from the chieftain, in part explains an important transition of the 9th and 10th centuries. Thenceforward, the creation of new kingdoms, common among the descendants of Clovis or Charlemagne, ceased; only a formal act of the papacy under rare conditions was thought capable of legitimizing such later kingdoms as Hungary (1000), Sicily (1139), or Portugal (1143).

The church, which played so large a part in creating such a king, was active in prescribing duties; the coronation oaths and prayers insisted upon his obligation to protect the church, the defenseless, and the poor, to make war upon the heathen in the service of Christ, and to ensure that justice was done. It was chiefly in church councils that the king's duty to the whole people was emphasized against his relations with his warriors.

Even where, as with the Capetian dynasty between 996 and 1316, son succeeded father in unbroken descent, it was conventional to refer to the king as chosen by his people, and this became an active principle where there was no obvious claimant, as at the end of the Saxon or Hohenstaufen dynasties in Germany or in such exceptional cases as the founding of the Latin kingdom of Jerusalem in 1099. Among the larger kingdoms of the 13th century, only Germany, beset by frequent changes of dynasty and by the papacy's hostility to a hereditary empire, was still in practice an electoral state. Charles IV's Golden Bull of 1356 formally defined the procedures of election that remained in force in the empire until 1806, although after 1437 the throne was monopolized by the family of Habsburg. In Denmark, Sweden, and Poland the kingship was also formally and often practically elective, though hereditary right became absolute in France, England, and Spain.

Popes. If the imperial authority became progressively more confined, that of the popes made great advances, partly at the empire's expense. The foundation of papal authority lay, first, in the claim to inherit all the powers conveyed to St. Peter by Christ and, second, in the special position of the bishop of Rome. Until the 8th century, papal preeminence was complicated by the existence of jealous patriarchates of the East, not least the new Rome at Constantinople, whose emperor remained the nominal and sometimes the effective overlord of the city of Rome. By 700, however, most of the other patriarchs were subject to Muslim rulers, and Byzantine military weakness had forced such popes as Gregory I to take on most civil responsibility for the city of Rome. Dogmatic disputes in the Byzantine Empire over the veneration of icons (725–843) hastened a process of estrangement between the Greek Eastern and Latin Western churches that was to deepen eventually into near permanent schism. Rome then was left in solitary eminence in the West. Missionaries from Anglo-Saxon England, which had been converted by Roman agents, came to exercise a dominant influence upon the Frankish kings of the early 8th century; under Pepin the Short, Charlemagne, and the latter's son Louis I the Pious, strenuous efforts were made to enforce a single liturgy, canon law, and monastic observance, the authenticity of which was guaranteed by its use at Rome.

Until the 11th century, this confirming and legitimizing of action begun elsewhere was the predominant if not exclusive role of a papacy largely under the control of a series of such local Roman noble houses as the Crescentii and counts of Tusculum. The papacy favoured rather than led movements of active reform in the monastic and secular church. With the accession of Gregory VII, however, the papacy assumed the leadership of a movement that saw the inertia of the bishops and archbishops as the chief obstacle to ecclesiastical reform and as a consequence of excessive lay influence on their appointment and conduct. Accordingly, Gregory and his successors aimed at reducing the authority of the secular princes over the church (so provoking the long and bitter Investiture Controversy with the emperors Henry IV and Henry V) and at replacing secular authority with an ecclesiastical government based upon the written canon law and directed from Rome. By the pontificate of Innocent III (1198–1216), substantial successes had been achieved. The Fourth Lateran Council of 1215, attended by more than 400 bishops and 800 abbots from the whole of the Latin obedience and by representatives of all the greater princes, disposed of secular and ecclesiastical business on the widest scale.

Papal leadership

The relation of papal primacy to the powers of kings and emperors was full of ambiguities. When there was a formidable imperial presence in Italy, the popes might claim a general responsibility for the souls of the emperor and his subjects that would entitle them to intervene

widely in the affairs of the empire or even the right to direct every aspect of temporal life toward salvation. More widely, they claimed a special authority over those temporal princes whose lands lay within the papal sphere of temporal lordship (as with Sicily, recognized as a papal fief in 1139) or who had accepted papal overlordship in more than spiritual affairs (as with Portugal in 1143 or England under John in 1213).

The difficulties that beset a full realization of the papal vision of a Christian and priestly monarchy were both internal and external. Internally, the process of centralization of authority made for slow and expensive decisions and was thought to demand a political independence in Italy that, in turn, involved long and costly wars with the Hohenstaufen and their successors north and south of the Papal States. Both centralization and the need to levy taxes on the church at large aroused the distrust and resentment of the local hierarchy, which could be exploited by kings (such as Philip IV of France in his contest with Boniface VIII) who were determined to secure their own right to tax their clergy and to submit them to the royal law.

The rise of national consciousness that accompanied this resistance, as well as the exile of the popes at Avignon after 1309, made the pope's universal role as arbitrator in secular or ecclesiastical affairs harder to sustain. The double election of 1378 created a schism and weakened the position of the papacy. Because neither contestant would give way, the schism could be ended only by an external agency—a general council of the church held at Constance in the presence of the emperor Sigismund between 1414 and 1418. The energies of the abler reformers of the next 30 years or so were largely diverted to disputing the rival claims to authority of a monarchical papacy and a general council. With the failure of the most ambitious of these at Basel (1431–39), the papacy emerged from the struggle again in Rome and again enjoying the plenitude of power; but the chief beneficiaries of the struggle were the secular princes, who had secured valuable concessions of control over their clergy as the price of their support.

The aristocracy. *The greater aristocracy.* By 1100 a greater aristocracy had evolved over almost all the Latin West, marked by a combination of three elements. First, its members were normally the lords of a number of men bound to them by an oath of fealty and an act of homage, while they were themselves so bound to a king, a prelate, or the pope; the obligations such bonds involved were various, but the performance of military service was the most widespread and characteristic. Second, this aristocracy commonly exercised a large measure of judicial, financial, and administrative authority over its dependents. Third, this was a landowning aristocracy that rewarded its dependents with grants of lands (fiefs), much as its own wealth had been enhanced by grants from kings, and maintained large households from the proceeds of the estates retained in the lord's own hand—the domain.

Elements of the aristocracy

To this combination, or some elements of it, the term feudalism is commonly though inconsistently applied; Marxists sometimes further apply it to a particular form of agricultural exploitation, the manorial system. But none of these elements necessarily supposes the others: in England, it could be said that all land was received from the king, yet public authority remained unusually concentrated in his hands; in Germany, the greatest princes came to hold rights of jurisdiction from the emperor rather than land, and their reciprocal duties were very slight; in southern France and Italy, tenure for homage and service was rarer, but political authority was exceptionally fragmented.

Within the ranks of the greater aristocracy, certain distinctions came to exist. Originally, there seem to have been a limited number of very great families in Germanic society, defined by birth and sometimes uniquely described as free, but this division slowly gave way to others whose titles derived from "public" functions rather than birth alone. The term duke was widely applied to the lords of certain areas, which were incorporated in the Frankish empire without wholly losing their identity—*e.g.*, Bavaria, Burgundy, Brittany, Aquitaine, Saxony—and also to the lesser lords of the loosely constructed kingdom of the Lombards; the Scandinavian jarls or Anglo-Saxon earls after the reign of Canute (d. 1035) were similar. In origin the word duke (from Latin *dux*) meant military commander, and it was on the basis of military need that the majority of 10th-century duchies emerged; for similar reasons, there appeared the margraves of Italy and Germany, lords of borderland with a wider military authority. In Germany, duchies multiplied in the 12th century, as in the creation of Austria in 1156, when the title implied membership of the highest rank in the social and tenurial scale; in 13th-century France and 14th-century England, the term was revived for great lordships (appanages) created for the cadets of the royal family.

The most widespread of such titles originally denoting public office and only later social rank or landed wealth was the Latin *comes* (German *Graf*, Anglo-Saxon *ealdorman*), or "count." *Comes* originally meant companion or member of the king's household of specially trained warriors; the appointment of members of the Frankish king's inner circle to the earlier administrative districts of *gau* or *pagus* caused the word to be applied to an officer of Carolingian government, then to a hereditary holder of office and rights, and finally to the head of a noble landed family. The terms duke, marquis, and count were themselves no necessary guide to relative wealth or prestige, because some duchies were almost empty titles while the powerful lords of Flanders or Champagne were only counts. The institution of the *Reichsfürstenstand*, the class of imperial princes in late 12th-century Germany, was conceived as defining the highest rank of lay and church princes standing immediately about the throne. While the greater aristocracy of France of the 15th century enjoyed its rights only under the supervision of the Valois kings, the German class was buttressed with important privileges that gave it enduring importance and near sovereign powers.

Origins of the aristocracy

The origins of this greater aristocracy and its privileges were diverse. Some Roman senatorial families survived or absorbed their invaders; some descendants of independent chieftains of war bands that did not secure lasting kingdoms entered the Frankish, Anglo-Saxon, or Scandinavian nobility; the descendants of some specially favoured royal companions were able to hold onto the gains of their ancestors. Birth was from the outset probably an essential element of both exalted rank and access to royal favour, but important modifications to this took place between the 9th and the 12th centuries; slowly, the emphasis upon patrilineal descent and primogeniture became ever stronger, and the extended kin group gave way to the dynasty. The passing of public offices into hereditary possession, the growing importance of military considerations, and a concentration of wealth and influence upon a limited number of indivisible castles all contributed to this effect. Whereas the great Carolingian families of the 9th century derived their names from an ancestor, their successors named themselves after the area of their rule or their principal stronghold.

Entry into this later aristocracy was possible by a variety of routes. Throughout this period, the enduring hazard of central authority was that those appointed to maintain its interest would succeed in converting this representation into a right. In Germany even the unfree class of *ministeriales* sometimes succeeded in establishing such claims to the imperial fiefs and castles entrusted to their care and thus forced their way into the aristocracy. In France and England in the later Middle Ages, royal servants were commonly enriched by the opportunity to deprive or buy out those outside the circle of royal favour. There, too, in the 14th century a certain number of great merchants in the service of the crown were able to enter the ranks of the nobility; in Italy, however, the incompatibility of merchant adventure with noble birth had broken down much earlier. In later medieval Europe the emergence of more professional armies (especially in Italy and France during the widespread disorders of the 14th century) provided opportunities for successful soldiers of modest birth to rise into the ranks of an aristocracy coloured by ideals of an elaborate knightly code.

Lesser nobility. It was of the essence of high social rank that the aristocrat should have a large following of men who were themselves of free birth. Every great man, like

every king, was made great by his capacity to maintain a retinue and reward his followers. An estate was valuable less for its revenues in money and goods than for the men whose services could be secured from it. The noble retinue was held together by gifts of gold, horses, weapons, or hawks, while those who served their lord well might hope for a gift of land. The numbers of such followers were swollen by freemen who were driven by need to surrender their own land to the lord and to receive it back as a conditional grant; in return they received a protection modeled upon that extended to the lord's own blood kin. With increasing specialization of warfare, free birth tended to give way to the skills of cavalry warfare as the essential qualification for noble service; these knights (French *chevaliers,* German *Ritter*) might live as retainers in the lord's household or hold land from him—a knight's fee, or fief—coming only at an exceptional summons to his feasts, courts, or wars. Many enjoyed a large freedom in the government of their estates and came to form a lesser nobility, bearing arms, using their own seals, and living in more or less fortified manor houses. As the apparatus and conventions of knightly warfare became more elaborate and the influence of the courtly romances more pervasive, there was a marked convergence of the ethics of noble birth and knighthood. In the 14th century, the Flemish chronicler Jean Froissart saw nothing incongruous in referring to King Edward III of England as a noble knight.

Knights

The rise of the knight to this more exalted status was in part a function of the dissolution of the tight bonds of dependence his land tenure would once have imposed. This was a general phenomenon of the later Middle Ages, for the complexity of tenurial obligations made them increasingly inadequate either for defining status or for providing the lord with his honorable retinue. The later medieval principalities therefore owed their legal constitution to the powers of the lord in the exercise of his sovereign rights rather than to his personal claims on the services of his vassals; by a parallel development, the lord's household and following were commonly then paid for their services. Even at the lower levels of society, the same movement can be seen at work. In the 9th century, a great estate would normally have a proportion of household slave labour; by the 13th century, almost all the household servants would receive some wages, though food, lodging, and security still formed the bulk of their payment.

The church hierarchy. The greater aristocracy throughout Europe included a number of churchmen, for the sees of bishops and many monasteries had received wide grants of land, over which they often exercised more extensive rights than did their lay fellows, both as lords of tenants and as royal officers. Under Charlemagne and later princes, the state intervened to enforce universal acquiescence in the form of spiritual government over the whole body of the laity, and this could be burdensome or even oppressive. High office in the church remained almost wholly the prerogative of the aristocracy and later of the knightly classes. Between the 8th and the 15th century it has been calculated that not much more than one-third of the 2,000 bishops appointed to German bishoprics came from nonnoble families, and only five are known to have come from the dependent peasantry that formed the great bulk of the population. Certain monasteries and colleges of cathedral canons were explicitly reserved to those of the most carefully authenticated noble birth. Yet access to the highest church offices was in part dictated by other considerations; from the 11th century onward, royal or papal service and mastery of the disciplines of theology and canon law provided the means for men to rise on their ability alone. Suger—abbot of Saint-Denis, a monk of modest origins who became chief adviser to Louis VI of France and regent for Louis VII and died one of the most powerful men of Europe—and Thomas Wolsey—a butcher's son who rose to be cardinal and archbishop of York and chief minister to Henry VIII of England—illustrate the advancement that the church could provide, however rarely.

Bishops

The original nucleus of church organization had lain in the bishoprics, groups of which, from the end of the 8th century at least, formed provinces normally presided over by an archbishop or metropolitan. The special interest of the church in political concord, which derived not merely from its dedication to charity but also from the vulnerability and wide extent of its property, made it for long the natural ally of kings and emperors; the anathemas of the bishops were regularly employed to reinforce the sword of the Lord's anointed. Being, if aristocratic, at least not hereditary magnates, the bishops were the allies upon whom the Saxon and Salian emperors of Germany and the early Capetian kings of France largely depended as a counterpoise to their greater secular subjects. The royal administration was staffed and directed by the clergy, and the church's endowments were used to reward them. In return the bishops secured great privileges; the archbishops on either side of the Rhine—at Reims, Sens, Mainz, Trier, or Cologne—were at once powerful landowners and lords exercising a wide measure of delegated royal authority, and these were only among the most visible examples of a movement in progress throughout Europe. A leading object of the Gregorian reform movement in the 11th and 12th centuries had been to distinguish between the bishop's absolute obedience to canon law and his conditional obligation to the prince. In practice, the bishops continued to depend on royal authority for defense against grasping lay neighbours, for the enforcement of ecclesiastical discipline (particularly in matters of heresy), and, in the later Middle Ages, for protection against the growing anticlericalism of some of the educated laity and even the financial demands of the papacy.

The original constitution of the diocese rested upon the bishop and a small group of clergy living with him at the church where he had his *cathedra,* or seat. Over the years, this pattern altered substantially. Subordinate centres grew up within the diocese, some large and early ones served by groups of resident clergy but the great majority caring for only a small parish and served by a single priest. In western Europe, at least, the network of parishes was largely complete by the mid-13th century. Recruitment to these was wide; some houses of canons and wealthy parishes provided revenues for men of high birth and influence, while others were served by men drawn from the peasant population, who might be little more than domestic servants of the landowner whose family had built the church. The widespread grant of parish churches to monasteries and religious communities (as many as one-third of the parishes of a diocese could be so granted) and the prevalence of absentee clergy, such as pluralists holding several benefices or scholars engaged in study at the universities, meant that many churches were served by substitutes—vicars, who enjoyed only a proportion of the revenues of their office, often a quite inadequate one. Besides these, most parishes also provided some employment for a floating population of clerks in minor orders. With a rapid decline in the creation of new parishes in western Europe after the 12th century, it was the endowment of chantries, the setting aside of money and buildings exclusively for the saying of mass for the soul of the founder, that provided the greater number of new, if modest, benefices, though these were usually associated with other parochial or charitable organizations.

The determined efforts made first by the early Carolingians and then by the reformers of the 12th and 13th centuries to provide an efficient system of supervision and control over the local pastoral work of the diocese ultimately produced an administrative hierarchy parallel to, though partly distinct from, the pastoral one. The rise of the bishop's formal jurisdiction saw the appearance of a host of legal and financial agents, ranging from the powerful archdeacon to the humble summoner, whose task was to enforce attendance at the church courts. The increasing centralization of church government at Rome in the 13th and 14th centuries required the appearance of other officers, proctors of bishops and abbots at Rome, collectors of papal taxes, and, later, such disreputable figures as the itinerant peddlers in papal indulgences and dubious relics—the pardoners.

Regular clergy

By the mid-13th century there existed beside this hierarchy another one, the regular clergy, living under a formal and corporate rule more demanding than the minimum

canonical requirements of the seculars. Between the 5th and the 11th century this sector had been overwhelmingly monastic, composed of autonomous houses ruled over by an abbot with near absolute powers and devoted to the maintenance of the regular liturgical cycle; in early times there had been a great variety of rules of life for monasteries, but from the 9th century one became preeminent—that of St. Benedict, which envisaged a life of corporate self-sufficiency as the norm. In the 11th and 12th centuries a number of variations on this rule appeared, designed to heighten the emphasis upon manual labour and corporate poverty (such as the Cistercians) or solitary contemplation (as with the Carthusians); in a more striking departure, some houses of canons under the flexible rule of St. Augustine were, it was hoped, to combine monastic rigour of life with active parochial work, while military orders founded in the course of the Crusades in the Holy Land and Spain and on Germany's eastern frontier combined the yet more disparate profession of war with monastic ideals. All these were property-owning corporations, as were the houses of nuns and canonesses that lived under similar conditions. Their presidents, especially the abbots of the more well-to-do Benedictine abbeys, were often wealthier than many bishops and were drawn from a similar social background. Only among the Cistercian lay brothers was entry into the monastic life readily open to men of humble origin. The original followers of St. Francis of Assisi were often drawn from a much wider variety of classes, but by the end of the 13th century both they and the followers of St. Dominic, originally intended to be educated preachers trained to combat heresy, had become orders of friars with a strong academic tradition, excluding all but the most talented of the very poor. These men renounced all property (even corporate), were especially engaged in the work of preaching (notably in the towns), and traveled constantly. By 1300 the multiplication of religious orders had virtually ended; many of the most influential devotional tracts of the later Middle Ages were written by or for recluses, for groups seeking to live the devotional life outside the confines of conventional orders (as with the Beguines), or even for a lay audience.

Clerks

Beyond the regular and beneficed secular clergy was a large body of clerks, in minor orders or in none, who had the crowns of their heads shaved in the tonsure without proceeding further, thus securing some of the legal immunities of the clergy with few of their duties. The clerks of the royal or imperial chapels who formed embryo civil services represented an exceptional group of such men, but many more were to be found at the universities of the 12th and 13th centuries, and a still larger number were loosely attached to a parish church or joined a vagrant body of "hedge-priests" that canon law struggled for centuries to regulate or abolish.

Educated laymen. An important test for determining membership in the clergy was literacy. But in the 13th century (and occasionally earlier) there appeared in Europe a body of educated laymen of a kind that had not been seen there since the collapse of Roman secular education; lawyers and administrators in the royal service might have an entirely secular career, and most merchants were necessarily literate. The 13th century produced two celebrated author-kings, the Holy Roman emperor Frederick II and James I of Aragon (though even in the 14th century Edward III of England could barely write a few painful letters).

Between 1300 and 1500 the proportion of educated laymen rose steadily; in part, the change was manifested in the growing importance of lay patronage in architecture, poetry, and the production of devotional manuscripts, the latter only the most striking example of a much more general and active participation of the laity in the devotional life. On the other hand, the secular agents of government were jealous of ecclesiastical claims to privilege and immunity. Anticlericalism in western Europe was as old as the Christian state, but the lawyers who staffed the sovereign governments of the 14th century had an alternative theory of the state to set against that of the church, and clerks such as Marsilius of Padua, William of Ockham, and John Wycliffe were providing a theoretical justification for lay intervention in the affairs of the church as far-reaching as the claims of Pope Innocent IV for papal authority in the secular world had been a century earlier. At the opening of the 14th century, the French chancery was directed by two lawyers, Pierre Flote and Guillaume de Nogaret, who launched a virulent and largely effective attack upon the universal claims for the papacy that had been forcefully restated by Pope Boniface VIII. Though even the revolutionary Hussite movement in Bohemia (1419–36) failed to subvert the authority of the church, the autonomy of ecclesiastical government was under pressure throughout Europe, largely because there now existed an educated laity able to perform the tasks hitherto reserved to a uniquely literate clergy.

Other social groups. *Townspeople.* The urban society of the Roman Empire in the West was breaking down long before the deposition of the last emperor in the late 5th century, and it continued to fade with few interruptions until the 10th century. The estimated population of Rome fell from more than 1,000,000 in the 1st century AD to 40,000 in the 7th; nevertheless, it long remained the largest city of the Christian West, although tiny compared to the greater Muslim cities or Constantinople. Many Roman towns continued to be occupied, often because they remained, or became, the seats of bishoprics or abbeys and so centres at least of consumption or because their walls offered some shelter from a long series of invaders. Commercial activity continued in those ports of Italy still in touch with Byzantium and perhaps on a modest scale in some Lombard towns. It even increased in such northern ports as Duurstede in the Rhine delta, the Viking entrepôt at Hedeby (in Schleswig), and the Russian cities trading through the Black Sea. By the end of the 11th century, the recovery of urban life was more general. Merchants trading over long distances began to appear as an urban aristocracy, wealthy men anxious to secure a larger measure of control in the government of their towns. In Venice this development was already clearly visible, and the fleets and trade of this port stimulated a revival of town life throughout northern Italy. The origins of these early capitalists are much disputed: some may well have been fortunate peddlers, but more can be shown to have been members of the lesser aristocracy, or tenants or officers of great churches, with capital to invest in goods and transport. In Italy the participation of the landed aristocracy in the life and trade of the towns was shown by the presence of clusters of their tall stone towers within the city walls rather than on outlying hill tops.

Recovery of urban life

Increasing political stability on land and contact with the Levant by sea saw the rapid increase of such trading communities in size and influence. The Italian cities of Genoa, Pisa, Lucca, and Siena rose to challenge the earlier dominance of Venice and Milan. In Germany the Rhineland towns were already a political force to be reckoned with in the civil wars at the beginning of the 12th century, but they came to be overshadowed by the great prosperity and activity of the Baltic towns of the Hanseatic League, such as Lübeck, Hamburg, and later Danzig, and subsequently by the prosperity of such South German towns as Augsburg and Nürnberg. In Flanders, textile manufacture, based in part on wool imported from Spain and Britain, produced from the 12th century a precocious industrial community with a large unstable proletariat concentrated in such towns as Ypres, Ghent, Bruges, and Arras; among the northern cities, only these could compete in influence with the greater Italian centres such as the manufacturing town of Florence (with a population of perhaps as high as 200,000 in the 13th century, largely supported by its textile industry) or the equally large Milan, celebrated for its metalwork and, most notably, its armories. Paris, with a population estimated at 80,000 by the end of the 12th century, was already acquiring most of the qualities of a capital city as the centre of the fast-growing Capetian royal government and the home of the greatest of European universities.

By the 13th century, the Italian towns commonly contained a group of aristocrats by birth or by wealth long possessed whose political dominance was challenged by the more substantial of the merchants. Below these were

the retailers and masters of the smaller crafts and then the wage labourers, apprentices, and beggars, who were normally without a political voice but whose grievances sometimes broke out in violence and even bloodshed. The urban nobility of Italy was without true parallels north of the Alps, and it was the greater merchants, or merchant adventurers of the later phrase, who formed the directing elite in most towns. Although even at the end of the medieval period the towns' share in the wealth and population of Europe was still very limited (over most of the Continent perhaps not above one-tenth of the total), their influence was much greater. Access to the towns had long been an important agent in social change but became more so with the marked rise in the population of Europe in the 12th and 13th centuries. After the crisis associated with the Black Death, the continuing or growing prosperity of some 15th-century towns was in marked contrast to the widespread decline of agricultural production and profit. Politically, the merchant interests of the towns were of the first importance, for it was only they who could provide the large sums of ready cash with which the kings of the later 15th century established royal authority over the magnates. To the degree that the king could continue to enjoy the taxes of the burgesses of his towns, he could maintain or extend his authority; without them he was reduced to competing with his own magnates on little better than equal terms.

Agricultural society. The countryside during the Roman period was chiefly cultivated either by the slaves of the great villa estates or by more or less free cultivators, sometimes bound by the government to remain on their land in order to maintain a taxpaying population but otherwise not labouring under grave personal disabilities before the law. In the Germanic societies of the invasion period, a threefold division of the agricultural population was common—the people par excellence (the *karl, ceorl,* or *bôndhi*), free peasants cultivating their own land, bearing arms, and so participating in the public assemblies of gau or hundred; a more obscure group often described as freedmen (*aldiones* for the Lombards and Bavarians; *Leti* among the Germans, Franks, Frisians, and also perhaps in Kent), possibly freed slaves, possibly the survivors of an earlier conquered population who enjoyed limited rights but did not usually play an active part in the courts; and the thralls, slaves either captured in war, condemned to their state by the law, or reduced to it by penury. Such bondsmen might sometimes have their own huts, plots of land, and houses and therefore enjoy a minimal independence.

Germanic division of agricultural society

These forms tended to merge so that over much of western Europe by AD 1000 the characteristic villager (villein) held a substantial plot in the village fields but equally was expected to perform such onerous services on a lord's domain as plowing, reaping, and carting and was subject to his lord's will in much the same fashion as the earlier landless slave. In addition, the village community would usually contain other men with smaller plots of land (cottagers), whose rents in labour and goods were correspondingly lighter, and also a small number of slaves, in the old sense of the word. All these unfree cultivators could be described as serfs, however diverse their economic conditions. In parts of Europe, notably in Scandinavia and northern Germany and in southern France, the free peasantry still formed an important element in the population, and by the 14th century their ranks were swollen by numbers of villeins whom changing economic conditions had allowed to commute their servile obligations for fixed rents in money. The settlers who had been persuaded to take up holdings in the planned land clearances of the 12th and 13th centuries by offers of considerable freedom of tenure had reached the same goal by different means. At the other end of the social scale, the landless wage labourer was now much more common.

The timing of this process, whereby many of the earlier free peasants were first assimilated to the legal if not the economic conditions of Roman slaves and then increasingly recovered their personal liberty to become rent-paying tenants, was extremely uneven. The cycle was complete for much of Italy by 1200 and for most of France and England by 1400, but the free peasantry of Scandinavia, parts of eastern Europe, and Castile was only beginning to feel the pressure of a serf-owning class of landlords in the 14th and 15th centuries, at a time when it was fast becoming obsolete elsewhere.

Beggars and outlaws. A society that was at best only just above subsistence level maintained a large body of vagrants. Economic disasters such as plague or famine forced a desperate population to attack the crops of more fortunate neighbours; in the late 12th century, freelance mercenaries roamed Europe in search of employers and booty, while the 14th and 15th centuries saw more organized (and so more formidable) free companies of professional troops whose favoured fields of operation were France and Italy, where their captains traded their services like sovereign princes. All large towns either generated or attracted their share of beggars and petty thieves; in François Villon, 15th-century Paris produced a universal poet to express the pleasures and much more frequent miseries of this vagrant life. Town and country alike lacked any effective police force, and therefore, although the majority of known or suspected criminals could be dispossessed of land and property, even murderers were rarely apprehended. At times in 13th-century England only one in 100 murderers was ever brought to trial and convicted. The rest fled, many apparently into the forest to live like beasts or find an organized band of outlaws, idealized tales of which became widely current in the later Middle Ages in the legends of Robin Hood. The local community protected itself as best it could against such bands, but the assistance of a local knight at the head of his retainers could rarely be distinguished from the nuisance it was supposed to abate. The fate of these outlaws was bound up with that of the forests, and both were in decline by 1500. With the first signs of a recovery of population, however, vagrancy and unemployment were probably increasing.

The vagrant life

Women. A society directed by warriors and celibate clergy was not one in which women would exercise extended rights very often. After about 1100, patrilineal descent was almost exclusively the test of nobility, while matrilineal descent was often the test of serfdom. The property rights of women, though protected by canon and secular law, were confined; it was a cherished freedom for widows to be allowed to refuse a second match proposed by lord or kin. Practice, however, did not altogether conform to this appearance. In barbarian society in the period after the invasions, and sometimes long after, matrilineal descent was often important—the house of Charlemagne traced its origins back to a daughter of Arnulf, bishop of Metz. Although few queens ruled in their own right, many exercised great political authority, as in the minority of their sons; the regency of Blanche of Castile for Louis IX in France was a notable and successful example. The remarkable Queen Margaret succeeded in uniting the three kingdoms of Sweden, Denmark, and Norway under her regency in the Kalmar Union of 1397, an act that influenced the future of all Scandinavia. Similarly, although debarred from the priesthood by their sex, a number of women played a leading role in ecclesiastical affairs. St. Catherine of Siena and St. Bridget of Sweden played a major role in achieving the return of the papacy from Avignon to Rome in 1377; both were celebrated adepts of the spiritual life, the female contribution to which is also attested by the works of Julian of Norwich or Margery Kempe in England. The influence of women was also felt in their role as patrons, sometimes of Christianity itself, as when a number of the invading chieftains of the 5th and 6th centuries were first married to Christian princesses and then converted. At the turn of the 11th/12th century, Queen Margaret of Scotland was responsible for the thoroughgoing reform of the church in her kingdom, which brought it rapidly into the mainstream of the Latin church; another notable lady, Matilda of Tuscany, had been the last refuge of the reforming papacy for almost a generation.

As patrons of the arts and, above all, of poetry, Eleanor, duchess of Aquitaine and wife first of Louis VII of France and then of Henry II of England, and her daughter Marie, countess of Champagne, were the leading figures

of their century. At Marie's request, Chrétien de Troyes translated Ovid's *Art of Love* and also wrote one of the first courtly romances to be based on Geoffrey of Monmouth's Arthurian history. In Marie de France the courtly romance found a skillful female writer—appropriately, because these tales, which evolved from the masculine world of the chanson de geste, reveal the growth of a new social convention in which women had a larger part and a higher function. Foreshadowed in the diffusion of the cult of the Virgin Mary in the 11th century, this new convention was developed in the Italy of Petrarch and Dante.

THE OPERATION OF THE MEDIEVAL WORLD

The most striking feature of medieval society was its peculiar diversity and complexity. Although scholars often conceived the world as a hierarchy in which all power was mediated from God according to a single ordered descent, in practice four distinct types of structure coexisted, overlapping and modifying one another profoundly but each with its own laws and objects. The first was the economic structure, essentially a diverse and inefficient agricultural society with islands of commercial activity. The second was the seigneurial, the structure by which this economic activity was adapted to provide a surplus for a small class of lords and occasionally for great merchants. The third was ecclesiastical, in theory an autonomous economy of salvation in which all forms of secular life had their spiritual counterpart. The fourth—and for long the most tenuous—was the centralized monarchical structure of the sovereign state. The triumph of this last over the earlier claims of the church and magnate government marks the end of medieval society.

Economic patterns. Latin Europe by 1500 covered a great diversity of lands and climates. A first division was that between the heavy soils of Germany, northern France, and Britain and the predominantly lighter soils of the Mediterranean lands of Spain, Languedoc, and Italy, in which vines and olives formed an important adjunct to grain.

Medieval communities. Both main types of agriculture were conducted by cultivators who lived, where possible, in large settlements, with their churches, mills, and barns, the whole settlement often walled, as in the bastides of southern France, or at least hedged against animal and human marauders. Both economies contrast with those that existed on their perimeters and in the less fertile or more broken country of the interior. In the Celtic lands of Ireland, Scotland, and Wales and in Spain and the foothills of the Alps, as well as in Hungary and the Latin Balkans, a largely pastoral economy flourished, depending on flocks of cattle, sheep, or goats and producing a quite different pattern of living. As oxen provided the essential power for the cereal farmer's plow, and as milk, cheese, salt, and meat were as important to his diet as a minimum of crops were to the most pastoral of societies, so most medieval communities represented a precarious balance of forces between the needs of crops and beasts. Beyond these types of communities there existed various types of highly specialized settlements, such as the fishing communities of the North Sea coast, the salt evaporators of southwestern France, the fenmen, and the miners, sometimes solitary and sometimes organized in tightly knit communities, as were the tin miners of Cornwall and Bohemia. With few technological resources and poor communications, all medieval communities were conditioned largely by their environment.

Some of the Mediterranean communities of Italian cultivators had been organized as great estates (latifundia) in the late and post-imperial period; each tenant held only as much land as could support the needs of him and his family while he worked on the lord's estate. Very early, however, the comparatively widespread use of coinage allowed landowners to abandon such direct exploitation, which was clumsy and time-consuming, in favour of a variety of leases for terms of years or lives. By such means, the community became one made up of independent cultivators, each with his own field. Similar tenancies prevailed over much of southern France, where Roman law, much modified by custom and the decay of the judicature, continued to regulate contracts and the functions of the market.

The triangle formed by the Loire and Rhine rivers contained the chief area of nucleated cereal-growing settlements, though there were notable extensions of this into Britain to the west and into Franconia, Swabia, Bavaria, and the German east. In the Loire-Rhine region, with its heavy soils and wet climate, most of the earlier small enclosed fields of the Iron Age gave way to the characteristic open fields of the medieval vill, where the arable land of the community lay in large blocks cultivated by heavy, ox-drawn plows. The mechanical difficulties of turning such an implement and the need for effective drainage produced a characteristic effect of long narrow parallel strips running down contours of the hills. Such cultivation required a regular alternation of crops because there were few means available for restoring the fertility of the soil except allowing either half or one-third of the land to lie fallow each year. Similarly, the other resources of the land in pasture, woodland, water, and common grazing needed careful annual regulation because there was constant tension between the needs of humans, crops, and beasts. Although therefore a village might be divided among several lords, the village itself had a regulatory function from early times. Some sets of village bylaws survive from the 14th century.

Open fields of the medieval vill

Until the 13th century, this open-field cultivation continued to support the classical manorial organization. The lord drew his profit partly from his possession of a share of the vill's arable land, which was exploited for him by his tenants for some of the week, and partly from the exercise of his right to compel his tenants to use his ovens and mills at a price and to control and exploit the use of the surrounding wasteland. In practice such communities had always maintained a population of landless men—slaves earlier and labourers later—and there usually were tenants who owed rent or personal services of a less strictly economic variety. (Such free tenancy became widespread with the clearing of outlying lands in the 12th and 13th centuries, especially in the planned colonies along the frontiers.) The more elaborately centralized manorial economy flourished only under suitable and limited conditions; even where it existed, increasing internal trade and a greater circulation of money encouraged a movement whereby the domain was leased out and the lord allowed his tenants to commute their labour dues into cash rents. The Black Death of 1347–50 and further visitations of the plague later in the century may have carried off one-third of the population of Europe. Even where its impact was less, the relation between land and labour shifted drastically in favour of the tenant. Over most of western Europe, the agricultural community organized to provide labour on the lord's estate almost vanished, though the need for common action in the agricultural cycle did not.

In contrast to these tightly knit, often productive, and vulnerable agricultural communities stood the much looser society of the higher lands, where settlement was necessarily dispersed and where social bonds rested much more exclusively upon the ties of the kin or clan than they did in the nucleated villages. Even the arable farmers in a scattered community had more independence than did their lowland fellows. The Icelandic sagas written down in the 13th century, in manuscripts typically preserved in farmhouses rather than in monastic libraries, provide a vivid picture of such communities.

The increasing economic specialization of the period between 1100 and 1500, which saw vine growing and sheep rearing rise to the status of basic rather than supplementary occupations for whole communities, was made possible by a great increase in the volume of exchanges, itself a function of greater political stability. These exchanges took place preeminently in three settings: the markets, chiefly for local produce, held at short and regular intervals; the trading communities of the towns; and the occasional great fairs, annual events to which merchants traveled from the ends of Europe and the proceeds of which enriched such fortunate princes as the count of Champagne, lord of the fair towns of Provins, Troyes, Lagny, and Bar-sur-Aube.

Increasing volume of economic exchange

Urban growth. Early concentrations of population in settlements occurred for political, ecclesiastical, or defen-

sive reasons as often as for commercial ones; but the period from the 11th century onward saw the widespread rise of classes of men engaged in the commerce of exchange or manufacture and settled for that purpose in urban groups. Many of these were originally only merchants in a subsidiary sense; and many towns were barely distinct from large villages, being surrounded by the town fields cultivated by the citizens and containing within their boundaries numerous livestock and small patches of cultivated ground. Yet, a common interest among merchants or craftsmen produced associations of considerable importance. Merchant guilds developed—groups of men whose interests extended far beyond the political horizons of the lords of most towns, anxious for the reduction of tolls and in need of their own courts of justice appropriate to the urgent demands of itinerant commerce. It was these who led the struggle for urban autonomy in Europe north of the Alps—a movement that almost always involved conflict with the local lords, especially bishops and abbots, but was often favoured by princes such as the counts of Flanders or Henry the Lion, duke of Saxony, in the German east. In this way emerged the juridical phenomenon of the town as a corporate person living within a pattern of territorial lordships. Similarly, such towns acted corporately, much as if they were landed magnates, seeking to subordinate neighbouring communities to the authority of the city magistrates, to compel the countryside to acknowledge the legal and economic primacy of the urban centre, and to divert profitable trade routes to their own advantage. The 12th-century crusading movement reflected such local hostilities—the Byzantine monopoly enjoyed by Venice was challenged by the direct access to the trade of the East offered by the crusader states, often maintained by the rival fleets of Pisa, Genoa, or Lucca. Long intercommunal wars, such as those between Pisa and Genoa or between Venice and Ravenna and Pula (now in Croatia), saw the rise of a small number of city republics governed by elected consuls combining birth and commercial substance in a unique blend. Within such towns there existed other interests also driven by their common economic interests into corporate action.

Associations of craftsmen and retailers formed themselves in guilds that had many objects beyond the commercial. Among the earliest of such guilds were those of prayer. Many guilds had their own chaplains and churches; some were responsible for such distinctive religious pageants as the cycles of plays performed by the various mysteries (or crafts) at Wakefield in England. Many also maintained a

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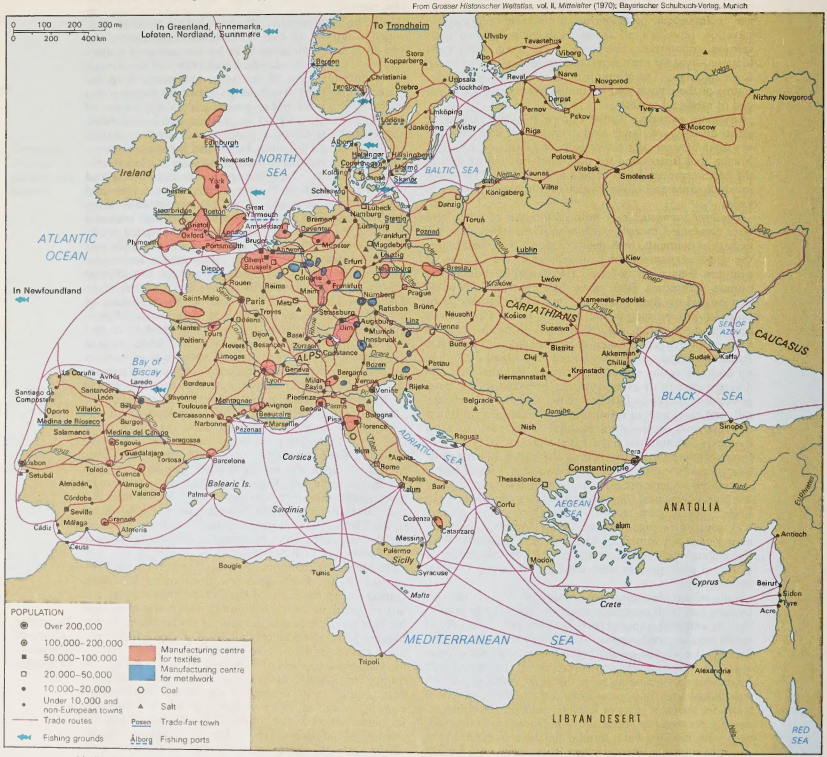


Medieval industry and trade about 1500.

form of insurance for their members, for the old, and for the widows and came to play a part in the regulation of their crafts—especially entry to them—and in the struggle for their interests against the competing ones of their suppliers or of related trades. The interests of the masters of these crafts were often opposed to those of the greater merchants, thus producing a struggle for control of the machinery of town government. Equally, however, other divisions cut across this classification by trades. Within the guilds there was a struggle between masters and men, between those anxious to reduce competition and those bent on a larger independence. Occasionally, and most strikingly in the industrial towns of Flanders in the 13th and 14th centuries, this produced proletarian risings of wide impact; at Courtrai in 1302 an army drawn largely from the Blue-Nails, the hired dye workers, defeated the combined forces of the king of France and the count of Flanders; frequently, the larger Flemish towns acted to free themselves from the power of the count or to maintain their communications with the English wool trade against the pressures of France.

Struggles for the control of town government

Though an urban proletariat of this kind was rare in medieval Europe, conflict between an urban oligarchy of landowners or great merchants (the *popolo grasso* of Italy) and the lesser craftsmen and labourers (the *popolo minuto*) was extremely common; it was at its fiercest where the cities enjoyed great autonomy, especially in Italy, where there was no effective or extensive central authority to maintain order. Hence, there were frequent civil wars in the Lombard towns, complicated by their external relations with each other, with the papacy, and with the empire; and there was a wide variety of forms of communal government, ranging from such attempts at radical democracy as the rising of the Ciompi of Florence in 1378 to an increasingly dominant model of dictatorship such as that exercised by the Malatesta of Rimini, the Visconti of Milan, or even the Medici of Florence.

The independence of the Italian city-states, which was complete by the end of the 14th century, had rested in part upon the successes of the Lombard League against the empire in the late 12th century. North of the Alps, particularly in Germany and the German-settled lands of the east, towns established similar but rather more restricted liberties against the greater princes and formed into leagues of economic communal interest, of which the most notable was the Hanseatic League of Baltic towns, which secured a near monopoly of the profitable northern trade in timber, furs, wax, and amber. First clearly organized in the late 13th century, by the 14th the league was the dominant commercial force in northern Europe. In alliance with the Teutonic Knights and by an aggressive policy of embargo and blockade, it secured privileges superior even to those of the native merchants in Russia, Sweden, Norway, England, and Flanders. Only in the later 15th century did the league begin to decline, with the failure of the Knights, the increasing commercial activity of the western kingdoms, and the decline of the Baltic herring fisheries.

Urban independence on the Lombard or Hanseatic model was exceptional, however; in France, Spain, parts of Germany, and England the towns remained firmly within the framework of royal or princely government, not least because only the king could be relied upon to maintain political and fiscal stability at home and to negotiate commercial privileges abroad. Contingents from the towns formed a numerically formidable element in the royal army at Bouvines (1214), when Philip Augustus defeated a combination of Norman, Flemish, and imperial forces aiming to restore the earlier independence of some of the greater vassals. It was the financial support of the towns that was of importance in the triumph of the "new monarchies" of 15th-century France, Spain, and Tudor England.

Protection of the merchants

Forms of lordship. Upon these economic structures there rested a variety of structures of lordship. The earliest that can be discerned in the centuries after the migrations were extremely complex, being functions of a power that was at once one of property, of kinship, of public function, and even sometimes of priesthood; only in the course of the later medieval period did these elements of authority come to be distinguished and sometimes divided.

Serfs. The economic bases of lordship in its least complex form lay in the ownership of men: the large household of slaves was the lord's property, and they worked his land. They enjoyed no rights against their lord, and he was responsible for maintaining peace and regulating their duties; such households of slaves became rare quite early over most of Europe. Domestic slavery was still an active force in the Iberian Peninsula and southern Italy at the end of the Middle Ages, though only in Sicily and the Balearic Islands were slaves widely engaged in large-scale agriculture. The responsibility of the lord for his own domestic servants remained near absolute, and the successors of many household slaves were the serfs who settled on small plots of land. Like the Roman slave, the medieval serf had no public rights against his lord; he was *adscriptus glebae*—so bound to his land that he could not leave it, as much a part of its stock as the cattle. The lord, by virtue of holding the land, was responsible for all police jurisdiction over his unfree men in his own court. His serfs were unable to marry without the lord's consent; in theory, their goods were his to tax at will during their lifetime and to confiscate at their death; their children were born into serfdom; and in all disputes there was no appeal from the lord to any higher tribunal.

Practice diverged at least in part from this grim theory. The agricultural cycle in which these serfs lived was conservative and complex, and custom operated powerfully to maintain it. Correspondingly, the disputes of tenants with each other and with the lord were regulated essentially by local custom, which was proclaimed by the body of the tenants in the lord's court. The rights of the lord to the labour of his serfs through the year and at the chief seasons of plowing and harvest were also fixed by custom and were rarely (and slowly) altered except at times of sudden crisis. The rights of the lord to the property of the serf were equally confined, so that the serfs' duties were expressed as the obligation to render produce for the great feasts of the year or to take their grain to the lord's mill, their flour to his ovens, or their grapes to his wine press or to make fixed payments at the marriage of a daughter, a father's death, or entry into a peasant holding, whether by inheritance, marriage, or purchase. Any or all of the other services could be commuted for money payments also, and, in western Europe at least, the function of the lord's court in regulating serf labour on his demesne was becoming obsolete by 1500, though its other functions still had a long future.

In some parts of Europe, the duties of the serfs included services that are less comprehensible; the very intimate bond between serf and lord might contain elements more accessible to an anthropologist than to an economist or historian. In many cases, the autocratic power of the lord was mitigated not merely by force of custom but also by close and frequent personal contact. The plans of early manor houses and castles show no extensive private rooms for the lord's use; he dined with his servants in his great hall, where he meted out justice. There was, until the later Middle Ages, little provision for private gardens for the lord's use. All but very great men could be found working at their own harvest, and feasts in the hall brought together the whole village community.

The bond between serf and lord

The lord had need of other services beyond those of his house and arable land. The greater Carolingian estates had aspired to complete self-sufficiency with their complement of carpenters, smiths, potters, and weavers, free or unfree, as well as the usual haywards, shepherds, and beekeepers. Men personally as unfree as the serf might also undertake more responsible tasks; the *ministeriales*, preeminently of Germany, not only acted as bailiffs but even bore arms as knights, though in such cases the dignity of the occupation came ultimately to cancel the defect of birth.

Feudal bonds. Men of free birth were found throughout Europe, though in varying numbers, who recognized the authority of a lord for some purposes—holding land from him in return for rent or services less servile than those of the villein. Most areas of Scandinavian settlement, much of Saxony, and the Low Countries were marked by

numbers of such men, who often pronounced judgments in their lord's court or escorted him through his estates, providing a contingent of men-at-arms in war and rent-paying tenants in peace. Lordship of this kind stemmed directly from the ownership both of land and of some of its occupants; the profits of lordship were, however, drawn from much wider sources than the labour of serfs or the rents of free tenants. Either by grant or by usurpation, a great variety of forms of indirect taxation were open to the lord. The levy of tolls on rivers, bridges, or roads was perhaps the easiest source of revenue open to any man. Permission to hold a market in a vill was a right to be paid for and could also involve further revenues in payments for the holding of stalls and even a tax on individual transactions. Very great men might even mint their own coinage. Manipulation of its weight and quality could bring in considerable revenues, and, consequently, the currencies of France, Germany, and Italy were extremely fragmented and often unstable.

The most distinctive form of medieval lordship, however, was that which is often called feudal, from the Latin *feudum,* meaning "fief," which was its central feature. In essence this was a fusion of the earlier precaria, a grant of land made for a fixed term in exchange for services or rents, with the very general commendation by which a man placed himself under a lord's protection by becoming his man or vassal. Some of those who had served their lord well would receive from him a benefice of land or revenue as a reward; others in dire need of protection would surrender their own land to the lord to receive it back as a benefice from him. When the tenant's right to his land became hereditary and his tenancy, or fief, ceased to be a reward for past services and became the reason for services to be performed in the future, feudal tenure was fully developed. These processes can already be traced before the end of the 9th century in the Carolingian empire.

By the 12th century such tenure was to be found throughout Latin Europe. It was characterized by a number of symbolic acts. The first was homage, the process by which the man knelt and placed his hands between those of his lord, so putting himself at the lord's disposal and under his protection. The next was the oath of fidelity, sworn by the man to his lord, sometimes sealed with a kiss. Then came investiture, by which the lord handed over some token of the fief to his new man. This sequence was first fully described in the year 1127, but its various elements can be traced or inferred very much earlier, though they were not all necessarily found together. The bond so created was much more than a form of land tenure: it was first a human relationship, in which the lord assumed many of the rights and duties of a father and from which the man could escape only if the lord directly attacked his life or family. If the lord died leaving a child as heir, it was the duty of the tenants to maintain the heir's rights until he came of age; similarly, if a tenant died leaving children under age, their wardship was the lord's. Not the least of the man's obligations might be that of attending the lord at the great feasts of the year, which were at once parties, parliaments, and law courts.

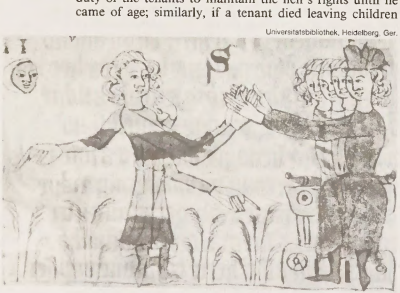
Lord and vassal

The duties of the lord to the tenant were usually only generally stated; he was bound to protect his man in war and peace, in the field, and in the law court. Carolingian legislation sought to ensure that every man had a lord to answer for him; a lordless man was a man in danger himself and a danger to others. The duties of the man to his lord varied enormously. Sometimes, even very early, the terms of his tenure were minutely defined. More often the general phrases of aid and counsel were called on to cover every possibility. As in the case of the servile tenant of the vill, however, a general subordination to the lord first became fixed by custom and then often commuted into a money rent. The aid the man owed was primarily military aid, essentially service with the full equipment of a knight—lance, sword, helmet, mail hauberk, and powerful horse. A great man's household usually contained a permanent body of these knights, who were often landless young men of good birth but no fortune; but the obligations of the enfeoffed knights living in the estates they held of their lords were early restrained, by custom at least, to a period of service in the field of 40–60 days and sometimes a limited period of garrison duty or castle guard at the lord's fortress. Not all personal aid, however, was military: there were also the sergeanties—fiefs held in return for other services. These ranged from fulfilling regular duties in the lord's household, such as steward, constable, or marshal (or even jester), to picturesque or purely honorific obligations, such as providing the lord with an annual goshawk, a leash of hounds, or a pair of gloves. All such services might come to be commuted for money payments; by 1200 it was common for the bulk of the knights liable for royal and even magnate service to settle their obligations by the payment of sums of scutage (literally shield money). Because, by then, service was seen as a burden on land and because this land might be in the hands of a church, a minor, or a woman or might be divided up among many heirs, such payments were a convenience to the tenant. A longer campaigning season and the high costs of a changing pattern of warfare often made money payment just as attractive to the lord.

Payment of scutage

Sometimes the lord might need financial aid for less strictly military reasons; again, custom came to distinguish the aids that he could levy from his tenants by right from those extraordinary ones for which the tenant's consent had to be sought. Practice varied, but the four most frequent were the knighting of his eldest son, the marriage of his eldest daughter, his setting out on crusade, or the ransom of his body.

Although in all these cases custom tended to strengthen the tenants' right in their land, there were three important traces of the lord's continued interest in what his ancestors had once granted: the relief, payable by an heir on entering into his inheritance; escheat, by which the lord recovered control of a tenure for which no direct heir could be found; and forfeit in the case of a tenant's treason or failure to perform his duties. The financial exploitation of these incidents of tenure and of the rights of wardship and marriage was among the most widespread of grievances against kings and great magnates in the 13th and 14th centuries.


Universitätsbibliothek, Heidelberg, Ger.

Detail from the Heidelberger Sachsenspiegel (Codex Pal. Germ. 164, fol. 6v), showing the homage ceremony, whereby the vassals put themselves under the protection of their lord by placing their hands between his. In the Universitätsbibliothek, Heidelberg, Ger.

The counsel that a tenant owed his lord also acquired a formal sense. The tenant's duty to attend his lord's court was of the greatest importance to the lord: it was the number and dignity of the suitors to his court that gave its judgments authority and stability. Around this central institution of the lord's court grew much of the apparatus of a sovereign state. The greater officers of the lord's household, most notably the steward, or seneschal, played an active part in overseeing the lord's estates, and in the later Middle Ages they often formed a council with regular sessions to audit the accounts of their lord's estates and developed their own code of legal precedents. In the 13th century, treatises upon the customs of such tenurial courts appeared in considerable numbers side by side with studies in Roman or royal government (the *Sachsenspiegel*

in Germany or the works of Beaumanoir in France may serve as examples). Only their homage to the king or emperor, with a variable liability to be summoned to his court, distinguished the greater magnates of France or Germany from sovereign princes.

Hierarchy of lordships

Theoretically, society could be conceived as a hierarchy of such lordships, with the sovereign at its head; but the practice was usually very different. In Germany the obligations of vassalage long retained traces of their servile origins, so that great men assumed them only with reluctance. It was correspondingly rare for a man to be the vassal of more than one lord; hence, a hierarchy of homages could appear in the late 12th-century *Heerschild* (a formal definition of social standing according to the number of intermediate lords between a man and the emperor) with the emperor at its head, the greater churches beneath him, then the imperial princes, who had done homage only to the emperor or the church, then counts, then noblemen, and so on. Even here, however, the consent of the other princes (the *Reichsfürstenstand*) was necessary for admission to the highest ranks, and the obligations such homage entailed were relatively very slight. Elsewhere—in France particularly—homage to more than one lord was frequent (the count of Champagne acknowledged 10 different lords for parts of his county), so that no such organizing principle could operate. What determined the permanence and vitality of tenurial networks was in part political and military circumstance, in part the extent to which some higher authority was able to intervene between lord and vassal, and in part the extent to which this lordship over men or tenants was able to absorb earlier administrative or public authority.

Acquisition of public authority. Some scholars have held that this passing of public authority into the domain of private right was the most essential and characteristic element of feudal society; it was certainly extremely widespread. In the 9th century there existed two types of local government that might be described as public: first, the residual Roman institutions of Gaul and Italy, with such modifications as the Carolingians had introduced, and, second, the public assemblies in which Germanic and Scandinavian societies had long been accustomed to do justice. In practice, these institutions had largely fused in the period since the barbarian invasions, so that the bulk of Latin Europe could be divided up into *pagi* (German *Gauen*) roughly comparable to an English shire in size and function, each presided over by a count (*comes, compte,* or *Graf*) who was the king's representative, most notably at the local court (the *mallus,* or *thing*). To this court all freemen brought their disputes, the later distinction between civil and criminal justice being as yet unknown. The law of the court might derive from tribal custom, as it had been preserved in either such laws as the Salian, Ripuarian, Burgundian, and Bavarian codes or the collective memory, or, farther south, it might be in the vulgar Roman law. In any case, it was the suitors of the court who determined the procedure and prescribed the appropriate forms of proof, such as the swearing of solemn oaths in special form, the undergoing of an ordeal (carrying a red-hot iron a prescribed distance, being thrown into deep water, holding a hand in boiling water), trial by battle, or, exceptionally, the scrutiny of sworn or even written evidence. All but the last of these were means of securing God's direct judgment rather than a merely human decision, but every preliminary step was determined by the court and particularly by a group of men learned in the law—*scabini, échevins, lagamen,* or *Rachinburgen.* Only in the 13th century, when the ordeal was condemned by the church and largely abandoned by the laity in favour of sworn and written evidence, did these lawmen give way to lawyers with special training.

The *pagus,* like the shire, was a military and fiscal unit as well as a legal one: it was presided over by a count whose responsibility it was to assess revenues, summon warriors for the royal army, and maintain the peace. To assist him in this task, lands were attached to his office, but he was also encouraged to secure the allegiance of the leading men of his *pagus.* In this way, to his authority as a royal representative, he added his personal claims over the *castellani,* lords of the principal fortresses of the district. These in turn were often able to exploit their military importance to assume the direction of such subdivisions of the *pagus* as the *centena,* or hundred. Similar in procedure and competence to the courts of the *pagus* or shire, such lesser jurisdictions were early and generally in private hands; some may have been from their inception.

In the widespread fragmentation of authority of the 10th and 11th centuries, the offices of count and castellan became hereditary over most of Europe, so that it was often no longer possible to distinguish the authority of the count from that of the lord or the suitor of the *mallus* from the vassal of the count. Under such conditions, the jurisdiction and procedure of the public court merged with that of the court of vassals. Meanwhile, jurisdiction in the county, having become attached to property, could also be divided; thus it often passed into the hands of lesser men who held it from the count as absolutely as he held his from the crown. Within the county there now existed liberties, or franchises, islands within which more or less of the king's justice was in the hands of a local lord and from which the count's agents were excluded. The greatest holders of franchises were the churches; the lay advocate who exercised temporal jurisdiction on behalf of such a privileged abbot or bishop had a wide competence that made such offices one of the greatest prizes of magnate competition. Some of these franchises were larger than counties or even extended over several. At the opposite end of the scale, all public authority over an area no larger than a vineyard might pass into the hands of a local knight subject to no restraints except those involved in his homage to a lord.

While the fiscal, legal, and military unity of the county either disintegrated or was reconstituted along the frontiers of a count's personal honour rather than earlier administrative or tribal divisions, there also appeared between the count and the king a number of intermediaries—sometimes distinguished as dukes or margraves—holding several counties. The duchies and margravates of the 10th and 11th centuries had originated as military commands, conferring on their holders only those rights over the counties of their area that were required by the pressing needs of defense; between the 10th and 13th centuries, these intermediaries fought a desperate battle against their sovereigns, on the one hand, and their neighbouring counts, on the other, to make this military authority (often over a former tribal district) into a more or less universal and exclusive jurisdiction. The results were extremely uneven. Some of the German duchies that emerged from the civil wars of the 12th and 13th centuries were coherent units, though they were smaller than their predecessors. The duchy of Normandy was a tightly organized unit until it passed to the French crown under Philip II Augustus in 1202–04; but the dukes of Aquitaine and Burgundy had only a tenuous and formal hold on their outlying vassals.

New forms of warfare. The growth of such lordships had originally owed much to military considerations. The decline of the popular courts and public jurisdiction had been accompanied by the appearance of innumerable private fortresses, often little more than a wooden stockade upon an earth mound (the motte) with a larger enclosure at its foot for stock and dependents (the bailey). These proliferated in the Loire-Rhine triangle in the 10th and 11th centuries, though they did not spread widely in England or Germany much before 1100. These fortresses were as important to defensive warfare as the mail-clad rider was coming to be in offense, for the possession of such strong points was a protection against all but the most formal and deliberate assault; few commanders could maintain a force for the time necessary to conduct this type of campaign. In the 12th century, the increasing number of stone-built castles, a more widespread use of paid troops, and the evolution of improved methods of siege warfare (some perhaps learned from the Muslims and Byzantines during the Crusades) altered the terms of warfare. Successful offense and defense required greater expertise and more extensive resources; correspondingly, the units of military independence tended to be much larger. The early motte-and-bailey castles could probably be built in a matter of

days, certainly weeks, and could be cast down yet more rapidly; but Château Gaillard, built by Richard I of England to protect Normandy from attack along the Seine valley, took years to build and cost more than three times the whole annual revenue of the duchy; it was still capable of resisting prolonged formal siege with artillery four centuries later. In the 12th and 13th centuries, series of these defenses were being put up by such princes as Frederick II in Sicily or Sancho I in Portugal, but, by the 15th century, gunpowder and engineering expertise were making such combinations of fortress and dwelling obsolete.

A parallel development began to affect mounted warfare about 1200. Although chain mail was expensive, it was far less so than the combinations of plate and mail (or finally plate alone) that appeared in the later Middle Ages; similarly, the horses needed to carry this heavier equipment were scarce and exceedingly costly. The fully armed knight of 1300 was a more formidable figure than his predecessor of 1100, but he was a rarer, a more expensive, and a more specialized commodity.

Decreasing military importance of knights

The military importance of the knight was reduced by the appearance of the more lightly armed men-at-arms or sergeants, and a trained infantry of pikemen and archers—crossbowmen, among whom the Genoese mercenaries excelled, and the longbowmen of English armies in Wales, Scotland, and France. The new armies of the 15th century were largely professional; they contained a high proportion of trained and well-armed infantry, which could be kept in the field for a whole campaigning season. The maintenance of such forces, with their extensive infrastructure of transport, victualing, and engineering, strained even the resources of a kingdom, and, over most of Europe, the near independent lordships of the great princes failed to survive. There were many great, rich, and privileged magnates in 16th-century Europe, but only in parts of Germany and Italy did they retain a complete local autonomy. It was rather by their influence on central government than their independence of it that they maintained political importance. By the 16th century, for the first time since the Roman Empire, centralized public authority covered much of Europe, though now within the frontiers of the national state.

Church government. Parallel with this structure of secular lordship stood that of the church, in which the opposing tendencies of central authority stemming from a single source and the collective authority of the community existed in a similar tension as in the court of a lord's vassals or in later royal councils.

The papacy. At the head of this church stood the papacy in Rome. Around the pope, conducting an ever-increasing volume of business, there grew up all the institutions of a centralized monarchy. The cardinals, chosen by the pope alone, formed the papal council, or the consistory. The 12th, 13th, and 14th centuries saw the rise of specialized departments to deal with legal matters, matters of penance, and finance (the Apostolic Camera); and, most important of all, it saw the rise of an elaborate chancery to direct the issue of the various forms of papal documents (known as bulls from the use of the *bulla,* a leaden seal used to authenticate many of them).

Growth of papal bureaucracy

The means of papal action beyond the immediate neighbourhood of Rome were provided by legates, either resident or specially commissioned, who enjoyed most of the sovereign authority of their master. The penalties of disobedience were excommunication (cutting off specific individuals from all human contact with the Christian community), interdict (the suspension of all the sacramental functions of the church—usually directed against an entire community or state), or, against princes, the launching of military expeditions with a papal blessing. The religious orders directly under papal protection, particularly the friars, provided a means of action and an intelligence service to set beside that provided by the collectors of papal taxes, often Italian merchants, and by the Inquisition. Founded in the early 13th century for the detection and extirpation of heresy, this institution was presided over by inquisitors drawn from the Dominican and Franciscan orders, but they answered directly to the pope and possessed an extensive staff of men outside the orders.

The bishops. The local organization of the church depended essentially upon the bishops, grouped under an archbishop or metropolitan specially charged with the consecration of the bishops of his diocese. He might hold provincial councils or even visit bishoprics to examine their administration; on occasions he could hear appeals from a bishop or take disciplinary action against one.

The bishop, originally elected in theory by the clergy and people of his diocese, was, in practice, appointed by some kind of compromise between the claims of the secular lord of the area, of the clergy of the cathedral church and diocese, and of Rome. By the 13th century, most bishops possessed a central administration consisting of several offices: a specialized court for dealing with church affairs, a chancellor who kept the bishop's seal by which his formal acts were authenticated and under whose supervision the records of the see were maintained, and a treasury for collecting the revenues—both from his estates and from more specifically ecclesiastical dues, such as a proportion of the tithes of the faithful or charges arising out of the ordinary exercise of his office. All these offices were staffed from the clerks of his household, increasingly to be distinguished from the chapter of beneficed canons, headed by a dean, who served the cathedral church. Although these canons were originally the bishop's household, by the 13th century they formed a compact corporation, sharing the revenues of the diocese with their bishop but often not appointed by him or subject to his strict control.

Within the diocese, the bishop had wide responsibilities: he alone could ordain clergy, consecrate churches, receive children into full membership of the church at confirmation, or impose penances for the graver sins. No one could teach or preach in the diocese without his permission, and he alone could admit novices to religious vows or bless the heads of religious houses. All judicial authority in the diocese was exercised by him either in person or through deputies, and without his sacraments the liturgical life would cease. In a more positive sense, he would teach and regulate the whole diocese as well as act as guardian of all church property, which could be neither received nor given away without his consent.

Much work remained in the hands of agents. Of these, the chief were the archdeacons, called the "bishop's eyes" since their duties were essentially disciplinary. Like the bishops, they made visits throughout their archdeaconries and held courts to which they summoned delinquent clergy and lay offenders against the regulations of the church in marriage, usury, wills, heresy, blasphemy, and the observance of feast days. Their arbitrary procedures and frequent assessment of fines made them widely feared and resented. Most archdeaconries were subdivided into districts presided over by archpriests or rural deans, usually chosen from among the parochial clergy.

Archdeacons

Parish organization. The chief centres of the devotional life of the medieval church were parish churches served by a priest and a variable number of assistants. The priest was normally appointed by the bishop on the presentation of the patron, whether a religious corporation or a layman. The parish was maintained out of the land attached to the church (the glebe) and the revenues from the faithful. From the 9th century, the payment of tithes, a tenth of the annual proceeds of agriculture and trade, had been obligatory for Christians; although many tithes passed to religious corporations or vanished into the hands of unscrupulous collectors, they remained the largest single element of many parochial revenues.

The parish clergy were principally charged with the salvation of their parishioners; this was to be achieved by the regular administration of the sacraments, baptism, mass, and, above all, the last rites. The priest was also expected to offer an example of good living, expound the basic precepts of the Apostles' Creed and Lord's Prayer, promote concord among his parishioners, admonish sinners, and denounce grave offenders to his archdeacon or bishop. Since the priest was often the only man able to read or write in his community, he would often have to act as an elementary teacher and village notary. At a time when the houses of the peasantry and even most manor houses were modest wooden structures with slight and crude

decoration, the parish church was a striking contrast, an elaborate stone building with walls bearing paintings of the gospel narrative and the Last Judgment and with vestments and church ornaments of considerable splendour. As the building dominated the settlement, so the feasts of the church provided a rhythm of ritual and recreation that in part supplemented, in part reinforced that imposed by the seasons of the agricultural year.

The regular clergy. Beside this hierarchy of the secular church stood the regular clergy. The earliest widespread communities of monks had been in theory strictly subordinate to their bishop. In practice, however, widespread recognition of the monastic life as the pattern of religious excellence, the active missionary work of such monks as St. Columban and St. Boniface, and the favour of great families gave the monasteries a position of substantial privilege. In the 11th century and later, such houses—led by Cluny—placed themselves directly under the protection of Rome as a means of excluding the bishop's authority; and, for the rest of the Middle Ages, quarrels over the bishop's right to secure an oath of obedience from the abbot, to visit the monastery to scrutinize its observance, and to exercise his office over the numerous churches and clergy attached to such abbeys were almost commonplace.

Direct protection of Rome

Parallel to the growth of such conflicts was the rise of congregations of regulars, in which houses of a common observance, such as those of Citeaux, Hirsau, or Prémontré, were organized in a hierarchy that allowed the order itself to discipline and correct its members, to legislate for the whole congregation, and to ensure a common rule of life among its far-flung membership. The way of life of the friars, with their dispersed and itinerent congregations, involved a more complex organization modeled upon that provided by St. Dominic in 1216. Under Dominic's organization, the order was divided and subdivided into provinces, ruled by masters, and chapters; elaborate regulations provided for the election of masters, and legislation for the order was promulgated in assemblies of elected representatives. Most of these features were taken over by the Franciscans before the end of the 13th century. Relations with the hierarchy of the secular church were sometimes strained because the friars were under the direct protection of Rome and enjoyed a correspondingly extensive, though much contested, immunity from episcopal jurisdiction. In this way, many of the religious orders were involved in a hierarchical system of centralized dependence parallel to that of the secular church.

Church councils. Although ecclesiastical authority, even in the orders, was exercised on a largely monarchical pattern, the church also contained important elements of corporate authority. The earliest genuine law of the church was substantially contained in the decrees of the ecumenical councils of the 4th and 5th centuries; and such gatherings continued to be held in the East, though their authority was not accepted in the West. After the formal ending of the Investiture Controversy, Pope Calixtus II summoned the First Lateran Council (1123), claimed as the ninth ecumenical or universal council of the church and the first to be held in the West. The legislation of this and its successors up to that of Vienne in 1311–12 was given very wide currency, although, according to the general opinion of canonists, it was of no greater binding force than the decrees of the pope alone. In the 14th century, opponents of papal authority, such as Marsilius of Padua, viewed the pope as an officer of the whole church subject to its control when assembled corporately in a general council. The double election of 1378 and the prolonged schism that followed allowed such theories a wider currency. It was the Council of Constance (1414–18) that ended the schism, but that of Basel (1431–49) introduced another—in part as a consequence of the belief that the pope was subject to the constant surveillance of the council, standing in the same relation to it as an Italian magistrate stood to the city that appointed him. Such corporate doctrine failed because the council became itself less and less representative; the limitations upon central authority that emerged were those imposed by the enlarged rights of secular rulers over the national churches.

The Lateran councils

The value of councils of bishops to promulgate decrees and pursue reform for a kingdom or province was generally recognized, but their ecclesiastical authority was, in theory, extremely limited. In practice, the legislation of provincial councils and even synods sometimes allowed local customs or variations from the universal law of the church, but this was by way of dispensation. Councils, however, were sometimes summoned by the king to assert his divine authority over his turbulent subjects, to enforce his policies with the double sanction of the secular and spiritual sword, or to confront the pope with the consensus of local ecclesiastical opinion as a means of putting pressure on him to abandon a policy. Such gatherings, however, rarely claimed to constitute autonomous local churches; and the nationalist claims made on behalf of the French church under Philip IV the Fair or for the English church under Henry VIII rested on the authority of the sovereign in his kingdom, not the corporate sovereignty of a council of the national church.

The universal claims of the papacy, even if practically confined to the Latin obedience, were constantly threatened by the strong secular particularism of Europe's medieval history. Between the 5th and the 12th century, the gravest danger was one generally subsumed under the term simony—that is, the constant likelihood that ecclesiastical rights would be subordinated to temporal interests and then fragmented, like them, to become merely aspects of private property. The hereditary lay abbots of the 9th century, the parish churches built as financial investments by their founders and bought and sold amid general acquiescence between the 7th and 12th centuries, and a widespread trafficking in offices, never wholly eradicated, all illustrate the gravity of this danger. These abuses were formally abolished and actually much reduced by the reformers of the 11th and 12th centuries, largely by means of a centralized law. Between the 13th century and the Reformation, the danger was that the political and linguistic boundaries within which the new national states were growing up would also divide the church. Against this danger, the traditional weapons of papal authority proved much less effective, and new ones were not forged before the end of the period.

Royal government. The growth of the centralized institutions of predominantly royal government required the rise of certain technical skills in the collecting and organizing of information. Until the 13th century there were no maps of great practical value; the statistics occasionally collected by medieval governments were often inconsistent and made according to erratic principles. Until near the end of the period, the usual methods of accounting and bookkeeping precluded most calculations performed by a modern government. The technology of transport was equally primitive; the best roads in the 15th century were still the Roman imperial streets, for all their thousand years of neglect, and winter flooding still affected most river systems in spite of some large-scale drainage works that had been undertaken in the Netherlands, Italy, and elsewhere. Under such conditions, a central government wholly free of "constitutional" restraints would still be obliged to leave its local agents a large measure of independence, and the custom of the neighbourhood was necessarily the chief regulator of political as well as social and economic relations.

The royal household. The seed from which all medieval institutions of central administration were to grow was the immediate personal household of the king; its members were the only permanent staff he had. The essential elements of the early royal household therefore provided the framework of the first departments of state.

The chief elements of the royal household were four—the hall, the chamber, the chapel, and the courtyard, with its horses and stables. The whole household, but in particular the hall, which was at once palace, law court, and dining room, was directly governed by the steward (*dapifer, seneschal,* or *drost*), under whose direction the guests were seated and the feasting conducted, while the wine was under the charge of a butler (*pincerna,* or *Oberschenk*). Under the later Merovingians in Gaul, the mayor of the palace (literally chief of the house) became a figure so powerful as first to overshadow and then replace his

Officers of the hall

king; elsewhere, though less powerful, the steward was the usual chief deputy of the king. Under the Capetians of France, he was charged with the annual scrutiny of the accounts tendered by the king's local bailiffs, the provosts; in Normandy, Jerusalem, and elsewhere he was the natural choice as regent in his lord's absence.

The chamber, the room in which the king slept or took private counsel, was also the natural place to store his treasure; hence, the chamberlains were often specially charged with the collection of revenue and handing it out as the king had need. The papal treasury was known as the Apostolic Chamber, and the papal chamberlains were widely entrusted with financial missions.

The chapel, containing the royal altar and relics (the term chapel derives from the *capella*, the short cloak of St. Martin preserved among the chief relics of the Carolingian royal treasury), was served by chaplains, to say the daily mass, assisted by a body of clerical assistants. As the chief and sometimes only literate members of the household, these men were responsible for drawing up such documents as the earlier kings required; among their number and often at the head stood the chancellor, whose special task was the authentication of royal acts, usually with the seal, which he kept.

This royal household was constantly on the move, carried on carts or packhorses—hence the great importance of the last two major household offices, those of the constable and marshal. The duty of the count of the stable (constable) was closely associated with the organization of the army, and hence the term came to be used of commanders of garrisons as well as the central household officer. The office of the marshal was originally more humble but shared the military fortunes of that of constable. In the 14th and 15th centuries, the constable and marshal came to a new importance as military commanders and correspondingly acquired judicial competence as presidents of the courts of chivalry, which dealt especially with military discipline, the division of ransoms, and the right to bear a coat of arms.

The growth of a permanent bureaucracy. These early household offices, with characteristically unspecialized duties, changed greatly under the impact of two forces. First, they had a tendency to become hereditary, much as the local offices of count or duke had done. Since the domestic service of the king, at least on public occasions, was itself a very great dignity, the most powerful families claimed the right to perform it, so that the office came to be the prerogative of great magnates who were too preoccupied elsewhere to perform their duties in person. Even the chancellorship sometimes became attached to certain archbishoprics—Reims or Mainz, for instance. Since the king's domestic needs continued, a distinction evolved between the hereditary dignitaries such as high steward or archchancellor and the men of much humbler rank who actually performed the routine duties of the household. Second, the increasing volume of business done in the king's name—judicial, administrative, or financial—demanded ever more elaborate records and a more extensive staff; therefore, the offices of government were less mobile, and a physical distinction became common between the constantly itinerant household about the king's person and the more cumbrous (though rarely wholly static) departments of permanent officials. Furthermore, the processes of government, especially in the chancery or (particularly well documented) the English exchequer, became arts or mysteries that demanded a staff of financial or legal experts with a specialized training. Thus were born the chief departments of state; well beyond the end of the medieval period, however, their principal officers were still considered the king's servants in a literal sense. This household character of public office made the distinction between loyalty to the king's person and loyalty to the office extremely hard to draw and frustrated many early efforts at "constitutionalism."

The chancery

Of these departments of state, the chancery was perhaps the most essential, for, without a means of transmitting a number of recognizably authentic commands or recording the business already done, no large measure of centralized activity was possible. The papal chancery was the earliest office to develop this skill on a large scale; the rhythm of the text and the forms of authentication for papal bulls were already formalized before the mid-12th century. Similar tendencies are found in England in the reign of Henry II and in France only a little later. (The urban notaries of Italy and parts of southern France were already using formalized business documents, though for a much more restricted area.) The second sign is the appearance of a substantial collection of records; apart from financial records, the essential element was the keeping of copies of documents issuing from the chancery, distinguished according to their character. Papal registers had probably been kept from a very early date, and a later copy of the Register of Gregory I still survives; an imposing and ever more complex consecutive series of original registers survives from the early 13th century. These were in the form of books. In England, where the great period of initial expansion lay in the period between 1190 and 1216, and in France, where the early royal archives have suffered much graver losses at the hands of time, the characteristic record was a series of parchment membranes stitched together to form long rolls. These archives evolved rapidly through the 13th, 14th, and 15th centuries, with the preservation of many more classes of document, including informal memoranda. Such records served the purposes of both governor and governed, for they provided precedents and the material for the reform and improvement of administration for the king's servants. They also provided authentic copies of title deeds or privileges for a subject at odds with his fellow or even the king himself. The conventions of the chancery had a marked tendency toward autonomy; efforts at magnate control in England or extensive reform of papal administration in Rome were partly frustrated by the elaboration and conservatism of chancery procedures that might at other times offer a useful defense against arbitrary government.

Among the most immobile elements of medieval government were those connected with the collecting and checking of the royal revenue. Until the 13th century, the only coinage current was the silver penny (or denier), so that large sums could only be transported packed in barrels of great weight. It was therefore natural for royal treasuries to appear as places of permanent deposit from which the itinerant court or army could be supplied at need. Often the treasury would also be the first site of any permanent archives. The audit of accounts from the sheriffs, provosts, bailiffs, or seneschals who were local collectors of royal revenue was a matter that could not be performed at a wholly itinerant court. Not only was it necessary for auditors and agents to have a known place and time at which to meet, but all except the least sophisticated forms of accounting required the keeping of records of former debts and present liabilities. Under Charlemagne, a *Capitulare de villis* envisaged a wide inquiry into the estates of the emperor, though only fragments of the returns survive; similar surveys were being made in 11th-century France and Germany on a small scale, but no early text can rival the record of Domesday Book (compiled in 1086/87), a survey of almost all of England, drawn up for William I the Conqueror. It is still preserved among the English public records.

The growth of financial records

The rise of the Exchequer as a semipermanent office and court for the hearing of accounts and the adjudication of financial claims was an early and striking feature of Anglo-Norman government on either side of the Channel. Certainly in existence soon after 1100, its first surviving pipe roll (annual statement of accounts) of 1130 is the earliest record of receipts of its kind for all of medieval Europe. In France the Capetian kings for more than a century used the Knights Templar as their bankers, so that it was not until after the withdrawal of his treasure from their hands by Philip IV the Fair in 1295 that a fully independent Chamber of Accounts emerged, with a comprehensive staff of financial experts.

The cumbersome machinery of such financial bodies was a grave impediment in times of political, financial, or military crisis, although, as in the case of the chanceries, due process offered some protection against arbitrary government. The frequent wars of the English kings and

their long absences in France, as well as their desire to escape the oversight of great officers approved by their magnates, encouraged the appearance of various financial systems within the household to compete with that of the Exchequer.

The king's council

As these departments of state became more fixed, professional, and independent, royal councillors who gave a political direction to the government acquired a distinct existence. In the early 13th century, the king's more or less permanent advisers began to take on a more formal character as the king's council. This council, often given definition by the taking of a common oath, was as omnicompetent as the king it served, and correspondingly, in times of political crisis, magnates or great assemblies sought to impose their nominees—as in England in the crisis of 1258–65 or France in 1356–57 or Aragon under Alfonso III. The direct and personal nature of the council's functions made such efforts almost always abortive. Only in Scandinavia, where the union of the three crowns involved prolonged regencies and uncertainties of succession, did the Råd enjoy a large independence from its king, though many German princes of the 14th and 15th centuries were compelled by their estates to accept a nominated council. In the 15th century, the powers of last resort possessed by the king and exercised in consultation with his council allowed the formation of offshoots of this council as prerogative courts of justice, administration, and finance.

Birth of parliamentary bodies. Over the same period, the larger assemblies in which some royal action had long taken place were also taking on a clearer form and defined functions, issuing in the assemblies of estates to be found over most of Europe in the 15th century. Three distinct influences lay at the origin of this development—ancient custom, feudal law, and administrative convenience. The Germanic tribes described by the Roman historian Tacitus in the 1st century AD gathered regularly in arms to determine matters of general importance. In some respects it was the size of such gatherings that decided the size of the kingdoms to which they elected chieftains; such gatherings of the warriors continued well into the period of Frankish rule, even in those areas where the powers of the king were very great. In Scandinavia, meetings of the *thing* never wholly passed into the power of magnates or royal officials, though elsewhere they changed radically.

Later, the king summoned his chief tenants by virtue of their obligation to give their lord counsel; the number of those who came was the critical test of the king's authority. The decline of French royal power in the 10th and 11th centuries or of German kingship in the 11th and 12th centuries can be plotted on maps by examining the composition of their great courts, especially at the chief feasts of the Christian year (or at principal landmarks in the life of the royal family, such as marriages and the knighting of the eldest son).

Since these large sessions of the tenants were also the most solemn courts a king could hold, great issues would be brought to it; since they were usually held at known times and places, those who desired the king's help in securing justice would seek them out. There were, however, further reasons why the king should try to enlarge the attendance at his courts or councils; the bonds of land tenure in most of Europe before 1300 had long ceased to articulate all the elements of society. To regulate the affairs of merchants, for instance, the feudal bond was worthless to secure counsel or consent. More important still, the obligations of feudal tenure no longer provided the forms of taxation needed for the defense of the state, and whatever methods of raising money supplemented them required the consent of the community in a new sense. The princes of the late 13th century claimed to be lords of states, not merely of associations of men; in their conflicts with the papacy, in their assertion of legislative authority, and in their claims to the financial support of the whole community, kings required a very general assent. Unless qualified representatives could be gathered, the king's will could not be known or the justification of changes publicized; the rise of the representative assembly is parallel to the rise of royal propaganda.

In the 13th and 14th centuries, these considerations produced a variety of experiments. In France after 1300, two meetings of the estates of magnates, churchmen, and burgesses were often held: one for the provinces of northern France (Languedoïl), another for the culturally different provinces of the south (Languedoc). Provincial gatherings of this kind were naturally prevalent in the states of Germany, where the dynastic disputes and poverty of many of the princes made them peculiarly subject to the pressures of their estates of knights, burgesses, and clergy; the imperial Reichstag, attended theoretically by the tenants in chief (chief vassals) of the emperor and representatives of the imperial towns, was intended to cover the whole of Germany but was as powerless as its central authority. In the kingdoms of Spain, signs of development appeared very early, representatives of the towns being summoned in 1188 in Leon; by the mid-13th century, the presence of townsmen in representative assemblies was customary throughout the country. In Aragon, magnates and knights were separate elements, but elsewhere the more usual pattern of the three estates of nobles, churchmen, and burgesses prevailed. The English gatherings to which the term Parliament came increasingly to be applied differed in important respects. From early in the 13th century, the king had summoned his tenants in chief to meet at the same time the central courts of justice and finance were in session; thus, royal officers, innumerable representatives of the shires and boroughs, and the magnates were gathering at one time. By the end of the 13th century, it was becoming common for special representatives to be summoned from the shires and the boroughs to attend these Parliaments; by the mid-14th century, their attendance had become the rule, but the clergy had largely withdrawn, except for the great ecclesiastical magnates who sat with the temporal lords, while the knights of the shire and the burgesses of the towns met together as a single body. Hence, there emerged a quite exceptional body with two chambers and a permanent representation of the nonnoble landowners to contrast with the much more widespread model of the three estates.

English Parliament

The business undertaken by these gatherings was extremely various. For reasons essentially of convenience, it was customary to publish legislation at such assemblies, as church councils had done for centuries. In Aragon and Catalonia, Scandinavia and much of Germany, the consent of the assembly was required to legitimize such enactments; custom produced much the same effect in England, and the Aragonese kings of Sicily (who replaced the Angevins there during the War of the Sicilian Vespers, 1282–1302) proclaimed the same principle. Yet more frequently they were assembled to assent to taxation, sometimes, though never wholly, saving the prince the difficulty of negotiating with each town or community for a contribution to the common need; they continued to constitute also the most weighty public court for the hearing of great causes. Though summoned essentially to consent to decisions made by the king and his inner council, such assemblies necessarily possessed a potential power to refuse or demand a precedent redress of grievances; and, as the powers of central government became greater, efforts to impose restraints on the prince in the name of the community became more widespread. Precocious efforts to subordinate royal government to the scrutiny of the magnates in Parliament, and even to require general assent to the appointment of officers of state, occurred in England between 1258 and 1265 and continued with some formal success in the 14th and 15th centuries. It was a successful struggle in the 14th century to require parliamentary consent to all extraordinary taxation that ensured the regular summons of such gatherings and made possible their use as an occasional forum of political discontent or even revolution, as in the reign of Richard II.

The Estates-General in France made similar efforts at political control of the kingship in the crises associated with the capture of King John II the Good, between 1356 and 1358 and again in 1413. The Cortes of Spain secured an even larger measure of success; in 1287 the magnates extracted from Alfonso III of Aragon the Privilegio de la Unión, which conferred upon the Cortes even the power

to depose an unjust king; here, too, assent to taxation was a prerogative of the assembly, though grants were made only by the burgesses. The weaknesses of these estates were very like those of the 15th-century councils of the church in their conflicts with the pope. Essentially they were occasions, rather than permanent bodies, which either were summoned by the king or—if gathered by any other means—were unrepresentative. Their control over the monarchy lasted only so long as they were in session, and exhaustion or particularism frustrated their long continuance. The kings could normally exploit either the localism or the diverging class interests of their estates to prevent any continuous supervision. In Catalonia in the 15th century, the Cortes possessed a General Council (Diputaçio del General), a standing committee to watch over the government, which not only granted but collected and spent any extraordinary taxation; but the forms of taxation divided the burgesses from the knights and nobles. In England there was less division of class interest but no effective or continuous supervision. In all cases, the resistance of the magnates was a precondition of large claims on behalf of the estates; yet a prolonged and successful magnate resistance destroyed that fusion of local and class interests upon which the estates depended for their vitality.

The growth of royal justice

Law and legislation. The need for general legislation arose largely from the great expansion of judicial business done by the king and his courts. The right and duty to do justice was so fundamental an element in early conceptions of government that almost every aspect of political authority was exercised in judicial form. The local organs of taxation and military recruitment were the courts of count, prince, or petty baron, to which freemen came to settle their differences; the English Exchequer was, in form and in practice, both a court and a counting house; the meetings of the estates as Parliament, Reichstag, or Cortes were courts before they were representative assemblies. Similarly, a centralized judicial system involved a centralized government and also a wealthy one.

Where custom was both decisive and localized, central courts had little attraction; where the modes of proof were intended to invoke divine rather than human judgment, there was little room for a theory of appeal; where travel was slow and literacy rare, centralized justice was extremely difficult to enforce. Therefore, the first technique available to the king who sought to enforce his law lay in the dispatch of trusted agents from his court to preside at local assemblies and to reduce the autonomy of counts or royal bailiffs. Under the Carolingians, special *missi,* often churchmen of high rank, performed this duty; in England, the itinerant justices formed the model for the earliest French *baillis* in the 12th century. Under the French king Louis IX, in the 13th century, friars were often employed as *enquêteurs* to scrutinize local government and amend the faults of local officers; under Louis's successors, the scrutiny was rather of their devotion to the king's interest.

As early as the 12th century, such devices were already giving a new importance to the king's central court, for matters of difficulty were often referred by the traveling judges to the king's own hearing; the existence of a body of such judges provided a volume of general legal experience at the centre and a certain degree of consistency of procedure in the provinces that pointed the way toward a single royal law and enhanced the value of a central judgment. At the same time, the king's court as the unique tribunal for disputes between his great tenants and as the last resort of injured litigants was attracting a greater volume of business. Although the ordeals and judicial combat never vanished entirely as methods of proof, they lost ground rapidly in western Europe in the 13th century to the procedures of written evidence and judicial inquiry; this made the theory of appeal easier to accept, and the practice was accelerated by two fundamental characteristics of medieval litigation. The first was the remarkable tenacity of litigants. The second was that judgments, to be effective, had to be accepted by both parties; the object of the court was to secure agreement and the voluntary submission of the unsuccessful litigant. In a society largely devoid of specific offices of enforcement, where those who appeared before the courts were often neighbours, this insistence upon the acceptability of judgments was essential. It made all the more valuable the judgment of a tribunal whose authority could not be refused. Hence, there emerged in all the larger states a variety of central courts.

The French Parlement

In France the regular gatherings at the king's court produced the distinctive institution of the Parlement, essentially an omnicompetent supreme court that began in the 13th century as a committee of the king's councillors with some expert legal assessors. By the mid-14th century this had become a fully organized and almost wholly professional body with three principal organs—the Grand Chamber, in which the decisions were pronounced; a Chamber of Petitions, which scrutinized appeals and distributed them to the appropriate tribunals; and a Chamber of Inquiry, which carried out the judicial inquiries upon which the final judgment rested. From its position as supreme court, the Parlement came to exercise a wide supervisory power even over the Chamber of Accounts; in this it continued to resemble the English Parliament as it had in its origins. Unlike the English institution, however, its nonprofessional element tended to diminish, and it achieved a substantial measure of independence in the appointment of its officers. But, having no control over financial supply and no representative or political basis, it was rarely capable of serious resistance to royal autocracy. With the collapse of English and Burgundian power in France in the late 15th century, a number of local *parlements* were created to serve the reunited territories, the earliest being that of Toulouse; in these, however, the crown's right of nomination prevented any serious threat to the legal unity of the realm.

In England the two courts of Common Pleas and King's Bench came to operate as supreme courts, especially for civil cases, while the royal monopoly over serious offenses was chiefly exercised by the itinerant justices of assize; over all these stood the high court of Parliament, which the litigant could petition for redress. The judicial authority of the king and the king's council offered the litigant a further source of appeal.

In Germany, political fragmentation prevented the evolution of a law unified by administrative practice, so that the need for a common code was reflected in the formal Reception of Roman Civil Law in 1495, a measure without immediate or widespread practical consequences.

Throughout the medieval period, central courts tended to attract an ever-larger proportion of litigation from the local courts. As a court of appeal, the French Parlement slowly eroded the importance of the local Grands Jours (the solemn sessions of the courts of the earlier great lordships), except in those cases in which these were themselves transformed into *parlements* at the end of the period. In England, police jurisdiction passed into the hands of justices of the peace, unpaid officials appointed by the crown from among the local landowners. All important civil litigation was conducted in London, leaving the old shire courts, once omnicompetent, only a shadowy existence. The letters of the Paston family show a group of minor Norfolk gentry engaged in a long series of lawsuits that kept the head of the family almost constantly in London as well as employing a considerable number of the professional lawyers who were so characteristic a product of the 14th and 15th centuries, both in France and England. These lawyers were among the earliest literate laity, the first trained secular administrators, and the chief agents of the unification of postmedieval states.

Revenue and taxation. The whole fabric of the centralized state depended on the mobilization of great resources for the crown. Even the earliest rulers had needed a hoard from which to reward their followers and to draw the gifts upon which relations with neighbouring chieftains depended. Such hoards were accumulated by successful plundering and the tribute of subject peoples; they were themselves the great prize of war, as when Charlemagne's forces sacked the Avars' Ring (chief fortress) in 795/796, and the treasure was carried across Europe by the cartload. The rich furniture buried with the ship of a petty king in East Anglia at Sutton Hoo in the 7th century shows how magnificent and how diverse these hoards must have

been. With the stabilization of settlement between the 9th and 12th centuries, the pursuit of plunder and tribute became a more marginal enterprise, still actively pursued by the Vikings and the Magyars (and later, in the 9th and 10th centuries, by the German settlers along the eastern frontier) but rarely available to most princes of post-Carolingian Europe. By this time, the fragmentary system of Roman taxation had also broken down, so that the central or royal revenues that existed were mostly those open to any great landowner. For many rulers, these resources were still largely in food rents, which the owners traveled about their estates to consume where they were produced. Throughout the medieval period, these revenues from the king's own estates were an essential element of his power; the extent and distribution of the royal domain were touchstones of his authority.

Beyond the revenue in kind produced on the king's estates or collected by his bailiffs, supplemented by a proportion of the trappings of his dead followers and any quasi-judicial fines that could be seized to his use, the king's revenue lay in services, such as his right to summon the army or to secure labour for his fortresses, cartage for his crops, or suitors for his courts. All these services and many of his food rents needed constant vigilance to enforce or secure. No prolonged expansion of central authority could rest on this anarchic foundation.

Such primitive sources of supply were the consequence of the almost complete collapse of a system of money exchanges across Europe, which was itself a consequence both of economic regression and perhaps a shortage of bullion; until the opening up of the central European silver mines on a large scale in the later Middle Ages, Europe had few supplies of ore for coinage. The monetary chaos of the 7th and 8th centuries was in part relieved by Charlemagne's introduction of the first medieval European silver coinage of commercial use, his pound of 240 pennies (deniers), coins of excellent quality and weight. Yet the multiplication of local mints and unstable values made even the abundant silver coinage of the 14th century awkward to use and offered innumerable opportunities for malpractice—from coining on a small scale by petty forgers to large but undisclosed devaluations by princes.

For all its inconveniences, however, the use of money to replace food rents or services rapidly became widespread as soon as the circulation of coinage and the evolution of a market made it possible. In the 10th century, the great domains of Italy were already being leased out; and, by the end of the 14th century, rent rather than labour was the characteristic peasant due everywhere in Latin Europe except in parts of Germany and central Europe. Similarly, it became increasingly common to commute the obligations of free tenants and feudal vassals to money payments; the very term aid (Latin *auxilium*), originally meaning simply the help a man owed his lord, had by 1200 come to mean a tax. The king could in theory impose what dues he liked, as could any other lord; these arbitrary tallages were of considerable importance in areas where, as in Capetian France, there were large towns on the domain to contribute to it. The exploitation of the forests also contributed in fines and licenses; market tolls and even a primitive form of sales tax went to swell the domain revenue. Though these profits could all be commuted and so more readily applied to the common needs of the kingdom, they still formed an extraordinarily complex and miscellaneous collection of rights of fluctuating value, which was far beyond the capacity of any central accounting system to assess or collect in detail—hence the importance of the local revenue collectors, stewards of the royal domain, sheriffs, provosts, vicars, and so forth. In general, the practice was to allow these officers to collect the normal profits of lordship for themselves in return for a fixed payment, accounting in detail only for such extraordinary revenue as heavy judicial fines or tallages. Fixed incomes of this kind suffered through a marked inflation over much of 13th-century Europe.

Rising costs of government in the 12th and 13th centuries required new and more comprehensive taxes little connected with either the ownership of land or the exploitation of vassals. The church, with its tithes, had long collected a form of income tax; under Innocent III the so-called charitable subsidy was imposed on the whole church by the papacy. Lay princes first employed a similar principle to finance the Crusades of the later 12th century by imposing a tax on the movable goods of their subjects. By the end of the 13th century, such taxes were frequent. In many respects they were the first manifestation of an act of sovereign government in Europe for centuries, being applicable to all subjects upon a uniform principle—although in practice the collectors often struck bargains with whole communities rather than pursue the complexities of universal assessment. The fifteenth and thirtieth granted by the English Parliament at regular intervals from the reign of Edward I were also employed occasionally in France, where a combination of a hearth tax and a variety of forms of sales tax (such as the notorious gabelle, a salt tax) became the most characteristic and permanent forms of national taxation. Customs dues, particularly on comparatively valuable and portable goods such as wool, wine, and cloth, also became widespread in the 13th century; it was at this time that elements of a genuine commercial policy first appeared in the conduct of princes, so that merchants began to secure legal and political rights as a class (as opposed to local privileges).

Loans from merchants and Jews

These merchants owed their political influence largely to the possession of large sums of cash or increasingly trustworthy systems of credit. Kings, and lesser rulers too, constantly found that their need for money was urgent but that their means of realizing it were slow. It took several years for a grant of a subsidy by subjects to be assessed and collected, but no army or even household could go without wages so long. Until the late 12th century, the sources of available credit were chiefly the Jews, exempt from the prohibitions of the church against usury, and goldsmiths. The Jews, generally prevented by law from holding land, were widely found in the towns, living sometimes under the protection of the church and often under that of the king, who exacted heavy sums in return for his protection and sometimes assumed the rights of a Jewish creditor himself. The life of the Jewish community was extremely precarious, for the Jews were constantly subject to the civil disabilities imposed by the church and were the most frequent victims of a wanton crusading zeal and sporadic violence; they found in kings harsh and inconsistent protectors who not infrequently expelled them from their lands as a measure of extortion or political appeasement.

THE WORLD OF THE SENSES AND THE MIND

The communities of the early Middle Ages lived on intimate terms with a largely hostile environment. Storms on sea and land, floods, pestilences, and famine were constant hazards. Even in the more densely settled parts of Europe, impenetrable forest and trackless fen covered large areas. These areas were often believed to be the haunts of demons and, in fact, provided refuge for brigands and outlaws as well as wolves and wild beasts. The uncultivated moorlands and mountain passes were safely crossed only in haste and with company.

Pagan religious survivals

The religious beliefs of the Germanic tribes gave way rapidly before the missionary fervour of Arian and Roman missionaries, but many pagan elements passed into the superficial Christianity of the first converts. Devotion to local saints was often (even deliberately) based upon earlier pagan cults, while churches were built on the sites of temples or sacred groves. The mere possession of such wonder-working relics as the Holy Lance of the empire was supposed to confer a title to the crown and a formidable military authority to its holder. There was a brisk traffic in such objects among princes, while the sacred groves and wells of the earlier religion rapidly took on the name of some local saint for the peasant population. Augury, the sacrifice of cattle, and a host of other pagan rites continued throughout the period, though the ecclesiastical police system was more and more successful in sharpening the distinction between acceptable devotion and witchcraft.

Christian life at the parish level necessarily reflected such conditions. In an illiterate society it was the ceremonial performance of the sacraments that was of paramount importance; indeed, preaching was a late and occasional

addition to the duties of the parish clergy. The blessing of harvests and houses and the averting of plague, fire, and invasion by regular formal intercession were the essential functions of the parish clergy. Correspondingly, communal disaster and outbreaks of anticlericalism were closely connected. For the salvation of the individual, the church required annual confession and very occasional taking of the sacrament. Private confession and private penance became the rule by 1100, but penance might be done by extensive traveling. By the 12th century, pilgrimages were made to the great international shrines of Jerusalem, Rome, Santiago de Compostela, or even St. Thomas of Canterbury, as well as to a host of lesser local shrines, insuring against the future or expiating past crimes. The Crusades, in part intended to restore the pilgrim road to Jerusalem, were themselves a means of securing full remission of sins for the participants. Their frequent failure or diversion to trivial or political ends made them a dying force after 1300, but the need for such concrete means of salvation continued. Papal jubilees and the organization of a system of indulgences secured by generous alms met this need, though at the same time they offered many opportunities for abuse.

Religious dissent

Until the 12th century, when Manichaeism spread through Italy and southern France, the orthodox church in the West was notably free of the doctrinal divisions that rent the Eastern church. Eradicated by prolonged and bloody war, this heretical view had little later influence, but the source of the success of Manichaeism—dissatisfaction with the wealth and pastoral inertia of the secular church—was to produce a multitude of dissident movements that laid stress either upon the defects of the propertied clergy or upon the possibility of direct illumination of the individual, notably by the reading of the Scriptures; already in the 12th century the Waldenses had adopted such views. In the late 14th century, John Wycliffe in England preached individual salvation and criticized the whole fabric of the church, sacramental and hierarchic. Wycliffe's doctrines met with little response in England but provided the starting point for the Hussite movement in Bohemia, where economic, political, and doctrinal revolution united to threaten the whole social and ecclesiastical order of eastern Europe.

In part this multiplication of dissent drew on the anticlericalism of the more educated laity and on wider knowledge of the Scriptures in vernacular versions, but it also coincided with the end of the period of monastic reform and development. While the fervour of St. Francis produced a new order to perform a vital function within the church, the devotional tendencies of the 14th and 15th centuries associated with the names of Meister Eckehart or Thomas à Kempis were largely devoid of institutional consequences. At the opposite extreme of this interior devotion was the proliferation of extravagant sects such as the recurring appearance of the flagellants in the years after the Black Death and its successors ravaged Europe. The prophetic form of much of the Scriptures, the frequency of disasters that appeared, at least locally, to portend the collapse of human society, and the general belief that the centuries after Christ's coming represented the last age of mankind produced a steady trickle of sects believing in the imminence of judgment or the new Jerusalem, encouraged by an easy distortion of the view of such academic prophets as Joachim of Fiore.

The role of community

Against the hostility of their world, seen or unseen, medieval societies also fell back upon a wide variety of communities vowed to mutual support. The minimal privacy of the characteristic medieval household gave all houses a communal quality. It was common for several generations to live, eat, and sleep under one roof, which often enough also covered the livestock. The earliest forms of Germanic settlement and organization rested upon the kin group, the early codes all supposing that the kin had absolute responsibility for its members. In the unstable society of the early Middle Ages, the bonds of commendation by which men bound themselves to a protector provided a substitute for the security and social cohesiveness of the earlier kin group. The medieval impulse toward the formation of communities bound together by oaths also may be seen in the trading guilds of the communes, in the councils of kings and princes, and even in the societies of rebels or robber bands.

The tightly knit character of most medieval communities was a result of the relative immobility of the population. While the church and warfare were international occupations in which a man might serve from one end of Europe to the other and though merchants traveled with their wares across a multitude of frontiers, the bulk of the agricultural population rarely journeyed more than a few miles from their village, and many townspeople were equally confined. News traveled slowly and inaccurately, borne by pilgrims, peddlers, bailiffs, and beggars; marriage outside the village was unusual; and local dialects sharply contrasted. On the edge of this society, however, some adventurous travelers were covering huge distances. The Vikings sailed south to the Mediterranean, east and south to the Black Sea, and west to Iceland, Greenland, and the coast of North America. In the 13th century, the Venetian traveler Marco Polo crossed the breadth of Asia to China, where several Franciscan missionaries were to follow. In the 15th century, Portuguese seamen groped their way south along the African coast in pursuit of gold and a sea route to the Indies, rounding the Cape of Good Hope in 1488. In 1492 a Genoese seaman, in the service of Ferdinand and Isabella of Spain, crossed the Atlantic and returned; remarkable though Columbus' voyage was, the rapidity with which its significance was assessed and exploited provided proof of how much the European view of the world was changing.

Technological advances

Primitive though the vessels and instruments of these navigators were, they showed a marked advance over the equipment of their predecessors, an advance that was widespread and accelerating in the 14th and 15th centuries. From the 9th century on, waterpower was extensively harnessed to mill flour, replacing the infinitely laborious querns of past millennia; it was also at work driving the hammers of the ironworkers and the first fulling mills, which revolutionized the social patterns of cloth working. In the 12th century, windmills also began to be used widely, while, at about the same time, changes in the forms of harness allowed horses to take over some of the plowing and carting formerly performed by oxen. In the 13th century, mining techniques for the first time allowed the driving of deep but drained shafts beneath the surface to the richer iron, copper, tin, and lead of Bohemia, Sweden, or Cornwall. By 1500 the demand for charcoal for smelting and timber for shipbuilding was already pressing hard upon the once inexhaustible forest of an older Europe.

As a consequence of these changes, the use of iron became common, even in the implements and houses of the poor. Metal cooking pots, glass bottles, and glazed wheel-turned pottery came into widespread use. Houses of stone or even brick often now had the chimneys and glass windows formerly found only in palaces. Domestic furniture of these centuries survives to show that it was no longer confined to crude benches, tables, and chests but was more carefully fitted and elaborately decorated. In the 15th century, the former cloth-working town of Arras expanded its manufacture of the tapestry hangings for which it would be long famous, while silk, linen, and cotton came into wider use. Sumptuary laws showed how much wider a range of society was able to dress in the materials and fashions that had once been the hallmark of the highest rank.

The earliest surviving medieval architecture is ecclesiastical; outside the area of continuing Byzantine occupation, these are small churches sometimes built out of the fragments of former Roman buildings and always derivative in style. Some of the greater Carolingian churches, however, were more ambitious in scale and conception, and the surviving 11th- and 12th-century Romanesque churches show the emergence of a wholly distinctive architectural convention in enormous and complex buildings. Gothic emerged in early 12th-century France and became the dominant style of the Latin West. In Italy the success of this style came late and was short-lived, for it was overtaken by the revived classical models before it had long

taken root; but over much of northern Europe the Gothic survived into the 20th century.

The earliest surviving medieval domestic architecture is found in a few stone houses of the towns and in the modifications of fortresses to serve more domestic purposes. By the 13th century, the stone palaces of princes were constructed with the skills first practiced in churches. Such planned towns as Aigues-Mortes foreshadowed the elaborate fortifications of many towns of the 15th century, within which numerous multistoried houses of wealthier merchants survive to the present. The single chamber of the lord's hall or the peasant's hut was increasingly giving way to the house divided into rooms, though in much of rural Europe there was little to distinguish the cabins of the poor of 1500 from those of a millennium earlier.

Recreation

The recreations of most ranks of society are poorly attested before the later Middle Ages. Among great men and warriors, the life of the hall and forest was preeminent. In the hall the long eating and heavy drinking of the lord's followers were favourite motifs of the heroic poetry once sung by household or itinerant poets, and feasts were an essential focus of social life. Coronations, weddings, and funerals were all celebrated with banquets. Pagan customs of punctuating the year with such events were either contested or taken over by the church; the gathering of the harvest and the celebration of Christmas were regular occasions of the kind, and from time to time the enthronement of a bishop produced a banquet of extraordinary splendour. The earliest texts stress the quantity (rather than the quality) of food and drink, but the more detailed later medieval records show that scarce or exotic foods and an extreme elaboration in their preparation were becoming the marks of ceremonial extravagance, the highest achievement of the pastrycook being such "subtleties" as the Holy Trinity surrounded by choirs of angels. Eating, drinking, and singing were supplemented by various forms of gambling, to which the Germanic peoples were so addicted that men were known to stake their own liberty on the fall of the dice and so condemn their descendants to slavery. Backgammon, chess, and (late in the period) card games were played by those with leisure and means.

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Ivory mirror case depicting chess players, early 14th century. In the Victoria and Albert Museum, London. Diameter 10.5 cm.

The principal recreations of the nobility in the countryside were hunting and fighting, both of which were originally conducted in an extremely dangerous way. The main beasts chased were the deer, boar, wolf, and bear, with rabbits, hares, and foxes serving as a lesser challenge; all were usually pursued on horses with packs of hounds, the variety and qualities of which were discussed in numerous later medieval treatises. The support of the chase was an important economic and legal institution. The rearing of the lord's dogs and other services for his hunting were conditions of some tenures, and the preservation of hunting rights was a source of revenue and a cause of oppression. Another honourable sport was falconry, first recorded in the 5th century. There was an appropriate bird for each rank of society, and in this sport women might participate more often than in the hunt.

The holding of sham battles for enjoyment and exercise became general in the 12th century, when the ransom of prisoners was an accepted means of support for skilled but landless knights. By the end of the century, the practice was so widespread as to attract the condemnation of the church and to represent, it was supposed, a threat to the stability of the state, since gatherings of armed men could readily become rebellions. In later centuries, this generalized melee gave way increasingly to highly formalized jousting between individual knights wearing armour especially adapted for a variety of possible rules of combat. In the 14th century, this was still a possible means of capture, ransom, or death; by the end of the 15th, it was almost entirely a sport.

For the less wealthy, the available entertainments were rarer and less elaborate but not perhaps much safer. Football, wrestling, or fighting with staves, regulated by few conventions, produced a heavy casualty rate, as did brawling in innumerable unregulated alehouses. Brewing was a cottage industry frequently engaged in by women, who sold their product subject to a seignorial right to examine the quality of the drink. In a society in which sugar was expensive even for kings and in which honey was prized but scarce, the thick beer and mead of the north was not only a focus of recreation but also an essential element of diet, as was the wine of the south.

Among the earliest of recorded arts was that of song, and a substantial body of medieval music has survived. The best-known is the ecclesiastical plainsong, whose traditional origins lie in the liturgical reforms of Pope Gregory I and which was elaborated into the complex polyphony of the 14th and 15th centuries, when for the first time the names of individual composers are recorded. The songs of troubadours and minnesingers of the 11th and 12th centuries show the rise of a sophisticated secular music that was increasingly accompanied by a variety of musical instruments. Well before 1500 the playing of music as an autonomous and often purely secular art was already established.

The decorative arts of painting and sculpture had undergone a similar progress. The rise of the professional painter of pictures to be considered as a creator in his own right is largely matched by the decline of the illumination of manuscripts, which reached a peak of elaboration in the mid-15th century just as the earliest printed books were heralding the end of the role of the hand-copied manuscript. Printing on wooden blocks spread rapidly in the second half of the 15th century, and, by 1500, presses were at work in every major country in Europe. Though the earliest printed books were extremely expensive and their purpose frequently liturgical, their potential importance was great because they could cater to the new market of the educated laity. These now included far more than the circle of great men who commissioned the splendid psalters and books of hours of the 14th and 15th centuries, which had overthrown a monastic monopoly of lavish manuscripts that had prevailed since the time of Cassiodorus and his copyists at Vivarium in the 6th century.

Education

The institutions and the subject matter of education had already proceeded according to a similar rhythm. The only schools of Europe in the 8th century, except perhaps in parts of northern Italy, were those attached often to monasteries and more rarely to bishoprics. Independent thought, even in theology, was extremely rare; theology remained under the long shadow of St. Augustine of Hippo, and the Greek learning and originality of John Scotus Erigena in the 9th century was little pursued. The rise of the new skills in dialectic in the 11th and 12th centuries produced two phenomena: first, a confidence in rational thought as a means of solving problems, especially those raised by the conflict of authorities, and, second, a number of teachers whose exceptional talents attracted scholars from the farthest ends of Europe. The self-confidence and European reputation of Peter Abelard reveal this move-

ment at its most distinctive. Around such teachers grew up either religious communities such as that of Saint-Victor of Paris or the earliest universities. In the 12th century, the lawyers of Bologna, the doctors of Salerno, and, above all, the theologians of Paris were becoming organized bodies governed by a chancellor; by the 13th century, the universities possessed their own statutes regulating the arduous courses of study toward recognized degrees. The crown of studies was the pursuit of the highest knowledge, theology. The forms of 13th-century university study gave rise to the characteristic theological achievements of the period, the summae of the Dominican St. Thomas Aquinas and the Franciscan St. Bonaventure. The founding of universities received a new impetus at the end of the 14th and 15th centuries, when they spread into Scandinavia, Scotland, and eastern Europe. It was in these years that most secured a large independence from external ecclesiastical government, and in the Councils of Constance and Basel the universities claimed a position of the highest authority.

Much of the earlier confidence in the capacity of intellectual endeavour according to the established forms of inquiry drained away in the 15th century. Logicians in the tradition of Duns Scotus and William of Ockham asserted the essential disparity of faith and reason; the canon law proved incapable of resolving the most pressing problems of ecclesiastical authority or of securing effective reforms; and the only literary forms that offered novelty and room for growth were the vernacular literature of the court and the classical poetry of the humanists. Whatever changes occurred in education were generated not in the universities but in the schools of such Italians as Vittorino da Feltre near Mantua or of the Brethren of the Common Life in the Netherlands. These first insisted upon the effects of education on the whole personality, where the numerous grammar, guild, and charitable schools had provided only a grounding in the mechanics of literacy. The retreat of the monopoly of the church in education stands beside the work of the explorers and the rise of the absolute monarchies as an important mark of the ending of medieval society. (Ma.Br.)

The Renaissance

Few historians are comfortable with the triumphalist and western Europe-centred image of the Renaissance as the irresistible march of modernity and progress. A sharp break with medieval values and institutions, a new awareness of the individual, an awakened interest in the material world and nature, and a recovery of the cultural heritage of ancient Greece and Rome—these were once understood to be the major achievements of the Renaissance. Today, every particular of this formula is under suspicion if not altogether repudiated. Nevertheless, the term Renaissance remains a widely recognized label for the multifaceted period between the heyday of medieval universalism, as embodied in the Papacy and Holy Roman Empire, and the convulsions and sweeping transformations of the 17th century.

The multifaceted nature of the Renaissance

In this period some important innovations of the Middle Ages came into their own, including the revival of urban life, commercial enterprise based on private capital, banking, the formation of states, systematic investigation of the physical world, classical scholarship, and vernacular literatures. In religious life the Renaissance was a time of the broadening and institutionalizing of earlier initiatives in lay piety and lay-sponsored clerical reforms, rather than of the abandonment of traditional beliefs. In government, city-states and regional and national principalities supplanted the fading hegemony of the empire and the Papacy and obliterated many of the local feudal jurisdictions that had covered Europe, although within states power continued to be monopolized by elites drawing their strength from both landed and mercantile wealth. If there was a Renaissance "rediscovery of the world and of man," as the 19th-century historians Jules Michelet (in the seventh volume of his *History of France*) and Jacob Burckhardt (in *The Civilization of the Renaissance in Italy* [1860]) asserted, it can be found mainly in literature and art, influenced by the latest and most successful of a long series of medieval classical revivals. For all but exceptional individuals and a few marginal groups, the standards of behaviour continued to arise from traditional social and moral codes. Identity derived from class, family, occupation, and community, although each of these social forms was itself undergoing significant modification. Thus, for example, while there is no substance to Burckhardt's notion that in Italy women enjoyed perfect equality with men, the economic and structural features of Renaissance patrician families may have enhanced the scope of activity and influence of women of that class. Finally, the older view of the Renaissance centred too exclusively on Italy, and within Italy on a few cities—Florence, Venice, and Rome. By discarding false dichotomies—Renaissance versus Middle Ages, classical versus Gothic, modern versus feudal—one is able to grasp more fully the interrelatedness of Italy with the rest of Europe and to investigate the extent to which the great centres of Renaissance learning and art were nourished and influenced by less exalted towns and by changes in the pattern of rural life.

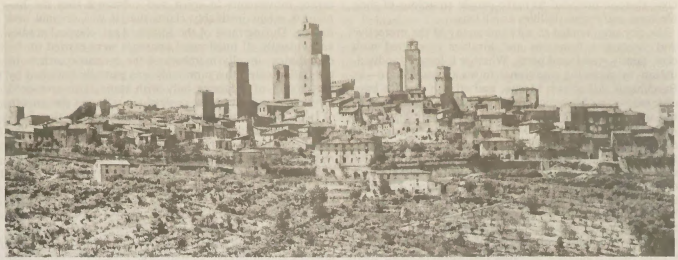
Renaissance developments in the arts, sciences, philosophy, and politics are discussed in many *Macropædia* articles. Additional treatment of Renaissance thought and intellectual activity can be found in HUMANISM and SCHOLARSHIP, CLASSICAL.

THE ITALIAN RENAISSANCE

Urban growth. Although town revival was a general feature of 10th- and 11th-century Europe (associated with an upsurge in population that is not completely understood), in Italy the urban imprint of Roman times had never been erased. By the 11th century, the towers of new towns, and, more commonly, of old towns newly revived, began to dot the spiny Italian landscape—eye-catching creations of a burgeoning population literally brimming with new energy due to improved diets. As in Roman times, the medieval Italian town lived in close relation to its surrounding rural area, or *contado;* Italian city folk seldom relinquished their ties to the land from which they and their families had sprung. Rare was the successful tradesman or banker who did not invest some of his profits in the family farm or a rural noble who did not spend part of the year in his house inside city walls. In Italian towns, knights, merchants, rentiers, and skilled craftsmen lived and worked side by side, fought in the same militia, and married into each other's families. Social hierarchy there was, but it was a tangled system with no simple division between noble and commoner, between landed and commercial wealth. That landed magnates took part in civic affairs helps explain the early militancy of the townsfolk in resisting the local bishop, who was usually the principal claimant to lordship in the community. Political action against a common enemy tended to infuse townspeople with a sense of community and civic loyalty. By the end of the 11th century, civic patriotism began to express itself in literature; city chronicles combined fact and legend to stress a city's Roman origins and, in some cases, its inheritance of Rome's special mission to rule. Such motifs reflect the cities' achievement of autonomy from their respective episcopal or secular feudal overlords and, probably, the growth of rivalries between neighbouring communities.

Rivalry between towns was part of the expansion into the neighbouring countryside, with the smaller and weaker towns submitting to the domination of the larger and stronger. As the activity of the towns became more complex, sporadic collective action was replaced by permanent civic institutions. Typically, the first of these was an executive magistracy, named the consulate (to stress the continuity with republican Rome). In the late 11th and early 12th centuries, this process—consisting of the establishment of juridical autonomy, the emergence of a permanent officialdom, and the spread of power beyond the walls of the city to the *contado* and neighbouring towns—was well under way in about a dozen Italian centres and evident in dozens more; the loose urban community was becoming a corporate entity, or commune; the city was becoming a city-state.

The typical 13th-century city-state was a republic admin-



Panorama of the town of San Gimignano, north of Siena, in central Italy, showing the towers and city walls that distinguished the Italian Renaissance landscape.
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istering a territory of dependent towns; whether it was a democracy is a question of definition. The idea of popular sovereignty existed in political thought and was reflected in the practice of calling a *parlamento,* or mass meeting, of the populace in times of emergency; but in none of the republics were the people as a whole admitted to regular participation in government. On the other hand, the 13th century saw the establishment, after considerable struggle, of assemblies in which some portion of the male citizenry, restricted by property and other qualifications, took part in debate, legislation, and the selection of officials. Most offices were filled by men serving on a rotating, short-term basis. If the almost universal obligation of service in the civic militia is also considered, it becomes clear that participation in the public life of the commune was shared by a considerable part of the male population, although the degree of participation varied from one commune to another and tended to decline. Most of the city republics were small enough (in 1300 Florence, one of the largest, had perhaps 100,000 people; Padua, nearer the average, had about 15,000) so that public business was conducted by and for citizens who knew each other, and civic issues were a matter of widespread and intense personal concern.

The darker side of this intense community life was conflict. It became a cliché of contemporary observers that when townsmen were not fighting their neighbours they were fighting each other. Machiavelli explained this as the result of the natural enmity between nobles and "the people—the former desiring to command, the latter unwilling to obey." This contains an essential truth: a basic problem was the unequal distribution of power and privilege, but the class division was further complicated by factional rivalry within the ruling groups and by ideological differences—Guelfism, or loyalty to the pope, versus Ghibellinism, or vassalage to the German emperors. The continuing leadership of the old knightly class, with its violent feudal ways and the persistence of a winner-take-all conception of politics, guaranteed bloody and devastating conflict. Losers could expect to be condemned to exile, with their houses burned and their property confiscated. Winners had to be forever vigilant against the unending conspiracies of exiles yearning to return to their homes and families.

Factional rivalry

During the 14th century a number of cities, despairing of finding a solution to the problem of civic strife, were turning from republicanism to *signoria,* the rule of one man. The *signore,* or lord, was usually a member of a local feudal family that was also a power in the commune; thus, lordship did not appear to be an abnormal development, particularly if the *signore* chose, as most did, to rule through existing republican institutions. Sometimes a *signoria* was established as the result of one noble faction's victory over another, while in a few cases a feudal noble who had been hired by the republic as its *condottiere,* or military captain, became its master. Whatever the process, hereditary lordship had become the common condition and free republicanism the exception by the late 14th century. Contrary to what Burckhardt believed, Italy in the 14th century had not shaken off feudalism. In the south, feudalism was entrenched in the loosely centralized Kingdom of Naples, successor state to the Hohenstaufen and Norman kingdoms. In central and northern Italy, feudal lordship and knightly values merged with medieval communal institutions to produce the typical state of the Renaissance. Where the nobles were excluded by law from political participation in the commune, as in the Tuscan cities of Florence, Siena, Pisa, and Lucca, parliamentary republicanism had a longer life; but even these bastions of liberty had intervals of disguised or open lordship. The great maritime republic of Venice reversed the usual process by increasing the powers of its councils at the expense of the doge (from Latin *dux,* "leader"). However, Venice never had a feudal nobility, only a merchant aristocracy that called itself noble and jealously guarded its hereditary sovereignty against incursions from below.

Wars of expansion. There were new as well as traditional elements in the Renaissance city-state. Changes in the political and economic situation affected the evolution of government, while the growth of the humanist movement influenced developing conceptions of citizenship, patriotism, and civic history. The decline in the ability of both the empire and the Papacy to dominate Italian affairs as they had done in the past left each state free to pursue its own goals within the limits of its resources. These goals were, invariably, the security and power of each state vis-à-vis its neighbours. Diplomacy became a skilled game of experts; rivalries were deadly, and warfare was endemic. Because the costs of war were all-consuming, particularly as mercenary troops replaced citizen militias, the states had to find new sources of revenue and develop methods of securing public credit. Governments borrowed from moneylenders (stimulating the development of banking), imposed customs duties, and levied fines; but, as their costs continued to exceed revenues, they came up with new solutions such as the forced loan, funded debt, and taxes on property and income. New officials with special skills were required to take property censuses (the *catasto*), calculate assessments, and manage budgets, as well as to provision troops, take minutes of council meetings, administer justice, write to other governments, and send instructions to envoys and other agents. All this required public space—council, judicial, and secretarial rooms, storage space for bulging archives, and both closed and open-air ceremonial settings where officials interacted with the citizenry and received foreign visitors. As secular needs joined and blended with religious ones, towns took their place alongside the church and the monasteries as patrons of builders, painters, and sculptors (often the same persons). In the late 13th century, great programs of public building and decoration were begun that were intended to symbolize and portray images of civic power and beneficence and to communicate the values of "the common good." Thus the expansion of the functions of the city-state was accompanied by the development of a public ideology and a

civic rhetoric intended to make people conscious of their blessings and responsibilities as citizens.

The city-state tended to subsume many of the protective and associative functions and loyalties connected with clan, family, guild, and party. Whether it fostered individualism by replacing traditional forms of association—as Burckhardt, Alfred von Martin, and other historians have claimed—is problematic. The Renaissance "discovery of the individual" is a nebulous concept, lending itself to many different meanings. It could be argued, for example, that the development of communal law, with its strong Roman influence, enhanced individual property rights or that participatory government promoted a consciousness of individual value. It could also be argued, however, that the city-state was a more effective controller of the loyalty and property of its members than were feudal jurisdictions and voluntary associations. In some respects the great merchants and bankers of the Renaissance, operating in international markets, had more freedom than local tradespeople, who were subject to guild restrictions, communal price and quality controls, and usury laws; but the economic ideal of Renaissance states was mercantilism, not free private enterprise.

Emergence of regional powers

Amid the confusion of medieval Italian politics, a new pattern of relations emerged by the 14th century. No longer revolving in the papal or in the imperial orbit, the stronger states were free to assert their hegemony over the weaker, and a system of regional power centres evolved. From time to time the more ambitious states, especially those that had brought domestic conflict under control, made a bid for a wider hegemony in the peninsula, such as Milan attempted under the lordship of the Visconti family. In the 1380s and '90s Gian Galeazzo Visconti pushed Milanese power eastward as far as Padua, at the very doorstep of Venice, and southward to the Tuscan cities of Lucca, Pisa, and Siena and even to Perugia in papal territory. Some believed that Gian Galeazzo meant to be king of Italy; whether or not this is true, he would probably have overrun Florence, the last outpost of resistance in central Italy, had he not died suddenly in 1402, leaving a divided inheritance and much confusion. In the 1420s, under Filippo Maria, Milan began to expand again; but by then Venice, with territorial ambitions of its own, had joined with Florence to block Milan's advance, while the other Italian states took sides or remained neutral according to their own interests. The mid-15th century saw the Italian peninsula embroiled in a turmoil of intrigues, plots, revolts, wars, and shifting alliances, of which the most sensational was the reversal that brought the two old enemies, Florence and Milan, together against Venetian expansion. This "diplomatic revolution," supported by Cosimo de' Medici, the unofficial head of the Florentine republic, is the most significant illustration of the emergence of balance-of-power diplomacy in Renaissance Italy.

Italian humanism. The notion that ancient wisdom and eloquence lay slumbering in the Dark Ages until awakened in the Renaissance was the creation of the Renaissance itself. The idea of the revival of classical antiquity is one of those great myths, comparable to the idea of the universal civilizing mission of imperial Rome or to the idea of progress in a modern industrial society, by which an era defines itself in history. Like all such myths, it is a blend of fact and invention. Classical thought and style permeated medieval culture in ways past counting. Most of the authors known to the Renaissance were known to the Middle Ages as well, while the classical texts "discovered" by the humanists were often not originals but medieval copies preserved in monastic or cathedral libraries. Moreover, the Middle Ages had produced at least two earlier revivals of classical antiquity. The so-called Carolingian Renaissance of the late 8th and 9th centuries saved many ancient works from destruction or oblivion, passing them down to posterity in its beautiful minuscule script (which influenced the humanist scripts of the Renaissance). A 12th-century Renaissance saw the revival of Roman law, Latin poetry, and Greek science, including almost the whole corpus of Aristotelian writings known today.

Earlier revivals of classical antiquity

Growth of literacy. Nevertheless, the classical revival of the Italian Renaissance was so different from these earlier movements in spirit and substance that the humanists might justifiably claim that it was original and unique. During most of the Middle Ages, classical studies and virtually all intellectual activities were carried on by churchmen, usually members of the monastic orders. In the Italian cities, this monopoly was partially breached by the growth of a literate laity with some taste and need for literary culture. New professions reflected the growth of both literary and specialized lay education—the *dictatores,* or teachers of practical rhetoric, lawyers, and the ever-present notary (a combination of solicitor and public recorder). These, and not Burckhardt's wandering scholar-clerics, were the true predecessors of the humanists.

In Padua a kind of early humanism emerged, flourished, and declined between the late 13th and early 14th centuries. Paduan classicism was a product of the vigorous republican life of the commune, and its decline coincided with the loss of the city's liberty. A group of Paduan jurists, lawyers, and notaries—all trained as *dictatores*—developed a taste for classical literature that probably stemmed from their professional interest in Roman law and their affinity for the history of the Roman Republic. The most famous of these Paduan classicists was Albertino Mussato, a poet, historian, and playwright, as well as lawyer and politician, whose play *Ecerinis,* modeled on Seneca, has been called the first Renaissance tragedy. By reviving several types of ancient literary forms and by promoting the use of classical models for poetry and rhetoric, the Paduan humanists helped make the 14th-century Italians more conscious of their classical heritage; in other respects, however, they remained close to their medieval antecedents, showing little comprehension of the vast cultural and historical gulf that separated them from the ancients.

Language and eloquence. It was Francesco Petrarca, or Petrarch, who first understood fully that antiquity was a civilization apart and, understanding it, outlined a program of classically oriented studies that would lay bare its spirit. The focus of Petrarch's insight was language: if classical antiquity was to be understood in its own terms, it would be through the speech with which the ancients had communicated their thoughts. This meant that the languages of antiquity had to be studied as the ancients had used them and not as vehicles for carrying modern thoughts. Thus, grammar, which included the reading and careful imitation of ancient authors from a linguistic point of view, was the basis of Petrarch's entire program.

Eloquence as the union of elegance, power, and virtue

From the mastery of language, one moved on to the attainment of eloquence. For Petrarch, as for Cicero, eloquence was not merely the possession of an elegant style, nor yet the power of persuasion, but the union of elegance and power together with virtue. One who studied language and rhetoric in the tradition of the great orators of antiquity did so for a moral purpose—to persuade men and women to the good life—for, said Petrarch in a dictum that could stand as the slogan of Renaissance humanism, "it is better to will the good than to know the truth."

The humanities. To will the good, one must first know it, and so there could be no true eloquence without wisdom. According to Leonardo Bruni, a leading humanist of the next generation, Petrarch "opened the way for us to show in what manner we might acquire learning." Petrarch's union of rhetoric and philosophy, modeled on the classical ideal of eloquence, provided the humanists with an intellectual dignity and a moral ethos lacking to the medieval *dictatores* and classicists. It also pointed the way toward a program of studies—the *studia humanitatis*—by which the ideal might be achieved. As elaborated by Bruni, Pier Paolo Vergerio, and others, the notion of the humanities was based on classical models—the tradition of a liberal arts curriculum conceived by the Greeks and elaborated by Cicero and Quintilian. Medieval scholars had been fascinated by the notion that there were seven liberal arts, no more and no less, although they did not always agree as to which they were. The humanists had their own favourites, which invariably included grammar, rhetoric, poetry, moral philosophy, and history, with a nod or two toward music and mathematics. They also had their own ideas about methods of teaching and study. They insisted upon the mastery of Classical Latin and, where possible,

Greek, which began to be studied again in the West in 1397, when the Greek scholar Manuel Chrysoloras was invited to lecture in Florence. They also insisted upon the study of classical authors at first hand, banishing the medieval textbooks and compendiums from their schools. This greatly increased the demand for classical texts, which was first met by copying manuscript books in the newly developed humanistic scripts and then, after the mid-15th century, by the method of printing with movable type, first developed in Germany and rapidly adopted in Italy and elsewhere. Thus, while it is true that most of the ancient authors were already known in the Middle Ages, there was an all-important difference between circulating a book in many copies to a reading public and jealously guarding a single exemplar as a prized possession in some remote monastery library.

The term humanist (Italian *umanista,* Latin *humanista*) first occurs in 15th-century documents to refer to a teacher of the humanities. Humanists taught in a variety of ways. Some founded their own schools—as Vittorino da Feltre did in Mantua in 1423 and Guarino Veronese in Ferrara in 1429—where students could study the new curriculum at both elementary and advanced levels. Some humanists taught in universities, which, while remaining strongholds of specialization in law, medicine, and theology, had begun to make a place for the new disciplines by the late 14th century. Still others were employed in private households, as was the poet and scholar Politian (Angelo Poliziano), who was tutor to the Medici children as well as a university professor.

Literary works of the humanists

Formal education was only one of several ways in which the humanists shaped the minds of their age. Many were themselves fine literary artists who exemplified the eloquence they were trying to foster in their students. Renaissance Latin poetry, for example, nowadays dismissed—usually unread—as imitative and formalistic, contains much graceful and lyrical expression by such humanists as Politian, Giovanni Pontano, and Jacopo Sannazzaro. In drama, Politian, Pontano, and Pietro Bembo were important innovators, and the humanists were in their element in the composition of elegant letters, dialogues, and discourses. By the late 15th century, humanists were beginning to apply their ideas about language and literature to composition in Italian as well as in Latin, demonstrating that the "vulgar" tongue could be as supple and as elegant in poetry and prose as was Classical Latin.

Classical scholarship. Not every humanist was a poet, but most were classical scholars. Classical scholarship consisted of a set of related, specialized techniques by which the cultural heritage of antiquity was made available for convenient use. Essentially, in addition to searching out and authenticating ancient authors and works, this meant editing—comparing variant manuscripts of a work, correcting faulty or doubtful passages, and commenting in notes or in separate treatises on the style, meaning, and context of an author's thought. Obviously, this demanded not only superb mastery of the languages involved and a command of classical literature but also a knowledge of the culture that formed the ancient author's mind and influenced his writing. Consequently, the humanists created a vast scholarly literature devoted to these matters and instructive in the critical techniques of classical philology, the study of ancient texts.

Arts and letters. Classicism and the literary impulse went hand in hand. From Lovato Lovati and Albertino Mussato to Politian and Pontano, humanists wrote Latin poetry and drama with considerable grace and power (Politian wrote in Greek as well), while others composed epistles, essays, dialogues, treatises, and histories on classical models. In fact, it is fair to say that the development of elegant prose was the major literary achievement of humanism and that the epistle was its typical form. Petrarch's practice of collecting, reordering, and even rewriting his letters—of treating them as works of art—was widely imitated.

For lengthier discussions, the humanist was likely to compose a formal treatise or a dialogue—a classical form that provided the opportunity to combine literary imagination with the discussion of weighty matters. The most famous example of this type is *The Courtier,* published by Baldassare Castiglione in 1528; a graceful discussion of love, courtly manners, and the ideal education for a perfect gentleman, it had enormous influence throughout Europe. Castiglione had a humanist education, but he wrote *The Courtier* in Italian, the language Bembo chose for his dialogue on love, *Gli Asolani* (1505), and Ludovico Ariosto chose for his delightful epic, *Orlando furioso,* completed in 1516. The vernacular was coming of age as a literary medium.

According to some, a life-and-death struggle between Latin and Italian began in the 14th century, while the mortal enemies of Italian were the humanists, who impeded the natural growth of the vernacular after its brilliant beginning with Dante, Petrarch, and Boccaccio. In this view, the choice of Italian by such great 16th-century writers as Castiglione, Ariosto, and Machiavelli represents the final "triumph" of the vernacular and the restoration of contact between Renaissance culture and its native roots. The reality is somewhat less dramatic and more complicated. Most Italian writers regarded Latin as being as much a part of their culture as the vernacular, and most of them wrote in both languages. It should also be remembered that Italy was a land of powerful regional dialect traditions; until the late 13th century, Latin was the only language common to all Italians. By the end of that century, however, Tuscan was emerging as the primary vernacular, and Dante's choice of it for his *The Divine Comedy* ensured its preeminence. Of lyric poets writing in Tuscan (hereafter called Italian), the greatest was Petrarch. His *canzoni,* or songs, and sonnets in praise of Laura are revealing studies of the effect of love upon the lover; his *Italia mia* is a plea for peace that evokes the beauties of his native land; his religious songs reveal his deep spiritual feeling.

Emergence of Tuscan as the vernacular

Petrarch's friend and admirer Giovanni Boccaccio is best known for his *Decameron;* but he pioneered in adapting classical forms to Italian usage, including the hunting poem, romance, idyll, and pastoral, whereas some of his themes, most notably the story of Troilus and Cressida, were borrowed by other poets, including Geoffrey Chaucer and Torquato Tasso.

The scarcity of first-rate Italian poetry throughout most of the 15th century has caused a number of historians to regret the passing of *il buon secolo,* the great age of the language, which supposedly came to an end with the ascendancy of humanist classicism. For every humanist who disdained the vernacular, however, there was a Leonardo Bruni to maintain its excellence or a Poggio Bracciolini to prove it in his own Italian writings. Indeed, there was an absence of first-rate Latin poets until the late 15th century, which suggests a general lack of poetic creativity in this period and not of Italian poetry alone. It may be that both Italian and Latin poets needed time to absorb and assimilate the various new tendencies of the preceding period. Tuscan was as much a new language for many as was Classical Latin, and there was a variety of literary forms to be mastered.

With Lorenzo de' Medici the period of tutelage came to an end. The Magnificent Lorenzo, virtual ruler of Florence in the late 15th century, was one of the fine poets of his time. His sonnets show Petrarch's influence, but transformed with his own genius. His poetry epitomizes the Renaissance ideal of *l'uomo universale,* the many-sided man. Love of nature, love of women, love of life are the principal themes. The woodland settings and hunting scenes of Lorenzo's poems suggest how he found relief from a busy public life; his love songs to his mistresses and his bawdy carnival ballads show the other face of a devoted father and affectionate husband. The celebration of youth in his most famous poem was etched with the sad realization of the brevity of life. His own ended at the age of 43.

> Oh, how fair is youth, and yet how fleeting!
> Let yourself be joyous if you feel it:
> Of tomorrow there is no certainty—

Florence was only one centre of the flowering of the vernacular. Ferrara saw literature and art flourish under the patronage of the ruling Este family and before the end of

the 15th century counted at least one major poet, Matteo Boiardo, author of the *Orlando innamorato,* an epic of Roland. A blending of the Arthurian and Carolingian epic traditions, Boiardo's *Orlando* inspired Ludovico Ariosto to take up the same themes. The result was the finest of all Italian epics, *Orlando furioso.* The ability of the medieval epic and folk traditions to inspire the poets of such sophisticated centres as Florence and Ferrara suggests that, humanist disdain for the Dark Ages notwithstanding, Renaissance Italians did not allow classicism to cut them off from their medieval roots.

Renaissance thought. While the humanists were not primarily philosophers and belonged to no single school of formal thought, they had a great deal of influence upon philosophy. They searched out and copied the works of ancient authors, developed critical tools for establishing accurate texts from variant manuscripts, made translations from Latin and Greek, and wrote commentaries that reflected their broad learning and their new standards and points of view. Aristotle's authority remained preeminent, especially in logic and physics, but humanists were instrumental in the revival of other Greek scientists and other ancient philosophies, including stoicism, skepticism, and various forms of Platonism, as, for example, the eclectic Neoplatonist and Gnostic doctrines of the Alexandrian schools known as Hermetic philosophy. All of these were to have far-reaching effects on the subsequent development of European thought. While humanists had a variety of intellectual and scholarly aims, it is fair to say that, like the ancient Romans, they preferred moral philosophy to metaphysics. Their faith in the moral benefits of poetry and rhetoric inspired generations of scholars and educators. Their emphasis upon eloquence, worldly achievement, and fame brought them readers and patrons among merchants and princes and employment in government chancelleries and embassies.

Humanists were secularists in the sense that language, literature, politics, and history, rather than "sacred subjects," were their central interests. They defended themselves against charges from conservatives that their preference for classical authors was ruining Christian morals and faith, arguing that a solid grounding in the classics was the best preparation for the Christian life. This was already a perennial debate, almost as old as Christianity itself, with neither side able to prove its case. There seems to have been little atheism or dechristianization among the humanists or their pupils, although there were efforts to redefine the relationship between religious and secular culture. Petrarch struggled with the problem in his book *Secretum meum* (1342–43, revised 1353–58), in which he imagines himself chastized by St. Augustine for his pursuit of worldly fame. Even the most celebrated of Renaissance themes, the "dignity of man," best known in the *Oration* (1486) of Giovanni Pico della Mirandola, was derived in part from the Church Fathers. Created in the image and likeness of God, people were free to shape their destiny, but human destiny was defined within a Christian, Neoplatonic context of contemplative thought.

> You will have the power to sink to the lower forms of life, which are brutish. You will have the power, through your own judgment, to be reborn into the higher forms, which are divine.

Political thought

Perhaps because Italian politics were so intense and innovative, the tension between traditional Christian teachings and actual behaviour was more frankly acknowledged in political thought than in most other fields. The leading spokesman of the new approach to politics was Niccolò Machiavelli. Best known as the author of *The Prince* (1513), a short treatise on how to acquire power, create a state, and keep it, Machiavelli dared to argue that success in politics had its own rules. This so shocked his readers that they coined his name into synonyms for the Devil ("Old Nick") and for crafty, unscrupulous tactics (Machiavellian). No other name, except perhaps that of the Borgias, so readily evokes the image of the wicked Renaissance, and, indeed, Cesare Borgia was one of Machiavelli's chief models for *The Prince.*

Machiavelli began with the not unchristian axiom that people are immoderate in their ambitions and desires and likely to oppress each other whenever free to do so. To get them to limit their selfishness and act for the common good should be the lofty, almost holy, purpose of governments. How to establish and maintain governments that do this was the central problem of politics, made acute for Machiavelli by the twin disasters of his time, the decline of free government in the city-states and the overrunning of Italy by French, German, and Spanish armies. In *The Prince* he advocated his emergency solution: Italy needed a new leader, who would unify the people, drive out "the barbarians," and reestablish civic virtue. But in the *Discourses on the First Ten Books of Livy* (1517), a more detached and extended discussion, he analyzed the foundations and practice of republican government, still trying to explain how stubborn and defective human material was transformed into political community.

Machiavelli was influenced by humanist culture in many ways, including his reverence for classical antiquity, his concern with politics, and his effort to evaluate the impact of fortune as against free choice in human life. The "new path" in politics that he announced in *The Prince* was an effort to provide a guide for political action based on the lessons of history and his own experience as a foreign secretary in Florence. In his passionate republicanism he showed himself to be the heir of the great humanists of a century earlier who had expounded the ideals of free citizenship and explored the uses of classicism for the public life.

At the beginning of the 15th century, when the Visconti rulers of Milan were threatening to overrun Florence, the humanist chancellor Coluccio Salutati had rallied the Florentines by reminding them that their city was "the daughter of Rome" and the legatee of Roman justice and liberty. Salutati's pupil, Leonardo Bruni, who also served as chancellor, took up this line in his panegyrics of Florence and in his *Historiarum Florentini populi libri XII* ("Twelve Books of Histories of the Florentine People"). Even before the rise of Rome, according to Bruni, the Etruscans had founded free cities in Tuscany, so the roots of Florentine liberty went very deep. There equality was recognized in justice and opportunity for all citizens, and the claims of individual excellence were rewarded in public offices and public honours. This close relation between freedom and achievement, argued Bruni, explained Florence's superiority in culture as well as in politics. Florence was the home of Italy's greatest poets, the pioneer in both vernacular and Latin literature, and the seat of the Greek revival and of eloquence. In short, Florence was the centre of the *studia humanitatis.*

Civic humanism

As political rhetoric, Bruni's version of Florentine superiority was magnificent and no doubt effective. It inspired the Florentines to hold out against Milanese aggression and to reshape their identity as the seat of "the rebirth of letters" and the champions of freedom; but, as a theory of political culture, this "civic humanism," as Hans Baron has called it, represented the ideal rather than the reality of 15th-century communal history. Even in Florence, where after 1434 the Medici family held a grip on the city's republican government, opportunities for the active life began to fade. The emphasis in thought began to shift from civic humanism to Neoplatonist idealism and to the kind of utopian mysticism represented by Pico's *Oration on the Dignity of Man.* At the end of the century, Florentines briefly put themselves into the hands of the millennialist Dominican preacher Fra Girolamo Savonarola, who envisioned the city as the "New Jerusalem" rather than as a reincarnation of ancient Rome. Still, even Savonarola borrowed from the civic tradition of the humanists for his political reforms (and for his idea of Florentine superiority) and in so doing created a bridge between the republican past and the crisis years of the early 16th century. Machiavelli got his first job in the Florentine chancellery in 1498, the year of Savonarola's fall from power. Dismissing the friar as one of history's "unarmed prophets" who are bound to fail, Machiavelli was convinced that the precepts of Christianity had helped make the Italian states sluggish and weak. He regarded religion as an indispensable component of human life, but statecraft as a discipline based on its own rules and no more to be subordinated

to Christianity than were jurisprudence or medicine. The simplest example of the difference between Christian and political morality is provided by warfare, where the use of deception, so detestable in every other kind of action, is necessary, praiseworthy, even glorious. In the *Discourses*, Machiavelli commented upon a Roman defeat:

> This is worth noting by every citizen who is called upon to give counsel to his country, for when the very safety of the country is at stake there should be no question of justice or injustice, of mercy or cruelty, of honour or disgrace, but putting every other consideration aside, that course should be followed which will save her life and liberty.

Machiavelli's own country was Florence; when he wrote that he loved his country more than he loved his soul, he was consciously forsaking Christian ethics for the morality of civic virtue. His friend and countryman Francesco Guicciardini shared his political morality and his concern for politics but lacked his faith that a knowledge of ancient political wisdom would redeem the liberty of Italy. Guicciardini was an upper-class Florentine who chose a career in public administration and devoted his leisure to writing history and reflecting on politics. He was steeped in the humanist traditions of Florence and was a dedicated republican, notwithstanding the fact—or perhaps because of it—that he spent his entire career in the service of the Medici and rose to high positions under them. But Guicciardini, more skeptical and aristocratic than Machiavelli, was also half a generation younger, and he was schooled in an age that was already witnessing the decline of Italian autonomy.

In 1527 Florence revolted against the Medici a second time and established a republic. As a confidant of the Medici, Guicciardini was passed over for public office and retired to his estate. One of the fruits of this enforced leisure was the so-called *Cose fiorentine* (*Florentine Affairs*), an unfinished manuscript on Florentine history. While it generally follows the classic form of humanist civic history, the fragment contains some significant departures from this tradition. No longer is the history of the city treated in isolation; Guicciardini was becoming aware that the political fortunes of Florence were interwoven with those of Italy as a whole and that the French invasion of Italy in 1494 was a turning point in Italian history. He returned to public life with the restoration of the Medici in 1530 and was involved in the events leading to the tightening of the imperial grip upon Italy, the humbling of the Papacy, and the final transformation of the republic of Florence into a hereditary Medici dukedom. Frustrated in his efforts to influence the rulers of Florence, he again retired to his villa to write; but, instead of taking up the unfinished manuscript on Florentine history, he chose a subject commensurate with his changed perspective on Italian affairs. The result was his *History of Italy*. Though still in the humanist form and style, it was in substance a fulfillment of the new tendencies already evident in the earlier work—criticism of sources, great attention to detail, avoidance of moral generalizations, shrewd analysis of character and motive.

The *History of Italy* has rightly been called a tragedy by the American historian Felix Gilbert, for it demonstrates how, out of stupidity and weakness, people make mistakes that gradually narrow the range of their freedom to choose alternative courses and thus to influence events until, finally, they are trapped in the web of fortune. This view of history was already far from the world of Machiavelli, not to mention that of the civic humanists. Where Machiavelli believed that *virtù*—bold and intelligent initiative—could shape, if not totally control, *fortuna*—the play of external forces—Guicciardini was skeptical about men's ability to learn from the past and pessimistic about the individual's power to shape the course of events. All that was left, he believed, was to understand. Guicciardini wrote his histories of Florence and of Italy to show what people were like and to explain how they had reached their present circumstances. Human dignity, then, consisted not in the exercise of will to shape destiny but in the use of reason to contemplate and perhaps to tolerate fate. In taking a new, hard look at the human condition, Guicciardini represents the decline of humanist optimism.

Guicciardini's pessimism

THE NORTHERN RENAISSANCE

Political, economic, and social background. In 1494 King Charles VIII of France led an army southward over the Alps, seeking the Neapolitan crown and glory. Many believed that this barely literate gnome of a man, hunched over his horse, was the Second Charlemagne, whose coming had been long predicted by French and Italian prophets. Apparently, Charles himself believed this; it is recorded that, when he was chastised by Savonarola for delaying his divine mission of reform and crusade in Florence, the king burst into tears and soon went on his way. He found the Kingdom of Naples easy to take and impossible to hold; frightened by local uprisings, by a new Italian coalition, and by the massing of Spanish troops in Sicily, he left Naples in the spring of 1495, bound not for the Holy Land, as the prophecies had predicted, but for home, never to return to Italy. In 1498 Savonarola was tortured, hanged, and burned as a false prophet for predicting that Charles would complete his mission. Conceived amid dreams of chivalric glory and crusade, the Italian expedition of Charles VIII was the venture of a medieval king—romantic, poorly planned, and totally irrelevant to the real needs of his subjects.

The French invasion of Italy marked the beginning of a new phase of European politics, during which the Valois kings of France and the Habsburgs of Germany fought each other, with the Italian states as their reluctant pawns. For the next 60 years the dream of Italian conquest was pursued by every French king, none of them having learned anything from Charles VIII's misadventure except that the road southward was open and paved with easy victories. For even longer Italy would be the keystone of the arch that the Habsburgs tried to erect across Europe from the Danube to the Strait of Gibraltar in order to link the Spanish and German inheritance of the emperor Charles V. In destroying the autonomy of Italian politics, the invasions also ended the Italian state system, which was absorbed into the larger European system that now took shape. Its members adopted the balance-of-power diplomacy first evolved by the Italians as well as the Italian practice of using resident ambassadors who combined diplomacy with the gathering of intelligence by fair means or foul. In the art of war, also, the Italians were innovators in the use of mercenary troops, cannonry, bastioned fortresses, and field fortification. French artillery was already the best in Europe by 1494, whereas the Spaniards developed the tercio, an infantry unit that combined the most effective field fortifications and weaponry of the Italians and Swiss.

New phase of European politics

Thus, old and new ways were fused in the bloody crucible of the Italian Wars. Rulers who lived by medieval codes of chivalry adopted Renaissance techniques of diplomacy and warfare to satisfy their lust for glory and dynastic power. Even the lure of Italy was an old obsession; but the size and vigour of the 16th-century expeditions were new. Rulers were now able to command vast quantities of men and resources because they were becoming masters of their own domains. The nature and degree of this mastery varied according to local circumstances; but throughout Europe the New Monarchs, as they are called, were reasserting kingship as the dominant form of political leadership after a long period of floundering and uncertainty.

By the end of the 15th century, the Valois kings of France had expelled the English from all their soil except the port of Calais, concluding the Hundred Years' War (1453), had incorporated the fertile lands of the duchy of Burgundy to the east and of Brittany to the north, and had extended the French kingdom from the Atlantic and the English Channel to the Pyrenees and the Rhine. To rule this vast territory, they created a professional machinery of state, converting wartime taxing privileges into permanent prerogative, freeing their royal council from supervision by the Estates-General, appointing a host of officials who crisscrossed the kingdom in the service of the crown, and establishing their right to appoint and tax the French clergy. They did not achieve anything like complete centralization; but in 1576 Jean Bodin was able to write, in his *Six Books of the Commonweal*, that the king of France had absolute sovereignty because he alone

Absolute sovereignty

in the kingdom had the power to give law unto all of his subjects in general and to every one of them in particular.

Bodin might also have made his case by citing the example of another impressive autocrat of his time, Philip II of Spain. Though descended from warrior kings, Philip spent his days at his writing desk poring over dispatches from his governors in the Low Countries, Sicily, Naples, Milan, Peru, Mexico, and the Philippines and drafting his orders to them in letters signed "I the King." The founding of this mighty empire went back more than a century to 1469, when Ferdinand II of Aragon and Isabella of Castile brought two great Hispanic kingdoms together under a single dynasty. Castile, an arid land of sheepherders, great landowning churchmen, and crusading knights, and Aragon, with its Catalan miners and its strong ties to Mediterranean Europe, made uneasy partners; but a series of rapid and energetic actions forced the process of national consolidation and catapulted the new nation into a position of world prominence for which it was poorly prepared. Within the last decade of the 15th century, the Spaniards took the kingdom of Navarre in the north; stormed the last Muslim stronghold in Spain, the kingdom of Granada; and launched a campaign of religious unification by pressing tens of thousands of Muslims and Jews to choose between baptism and expulsion, at the same time establishing a new Inquisition under royal control. They also sent Columbus on voyages of discovery to the Western Hemisphere, thereby opening a new frontier just as the domestic frontier of reconquest was closing. Finally, the crown linked its destinies with the Habsburgs by a double marriage, thus projecting Spain into the heart of European politics. In the following decades, Castilian hidalgos (lower nobles), whose fathers had crusaded against the Moors in Spain, streamed across the Atlantic to make their fortunes out of the land and sweat of the American Indians, while others marched in the armies and sailed in the ships of their king, Charles I, who, as Charles V, was elected Holy Roman emperor in 1519 at the age of 19. In this youth, the vast dual inheritance of the Spanish and Habsburg empires came together. The grandson of Ferdinand and Isabella on his mother's side and of the emperor Maximilian I on his father's, Charles was duke of Burgundy, head of five Austrian dukedoms (which he ceded to his brother), king of Naples, Sicily, and Sardinia, and claimant to the duchy of Milan as well as king of Aragon and Castile and German king and emperor. To administer this enormous legacy, he presided over an ever-increasing bureaucracy of viceroys, governors, judges, military captains, and an army of clerks. The New World lands were governed by a separate Council of the Indies after 1524, which, like Charles' other royal councils, combined judicial, legislative, military, and fiscal functions.

The empire under Charles V

The yield in American treasure was enormous, especially after the opening of the silver mines of Mexico and what is now Bolivia halfway through the 16th century. The crown skimmed off a lion's share—usually a fifth—which it paid out immediately to its creditors because everything Charles could raise by taxing or borrowing was sucked up by his wars against the French in Italy and Burgundy, the Protestant princes in Germany, the Turks on the Austrian border, and the Barbary pirates in the Mediterranean. By 1555 both Charles and his credit were exhausted, and he began to relinquish his titles—Spain and the Netherlands to his son Philip, Germany and the imperial title to his brother Ferdinand I. American silver did little for Spain except to pay the wages of soldiers and sailors; the goods and services that kept the Spanish armies in the field and the ships afloat were largely supplied by foreigners, who reaped the profits. Yet, for the rest of the century, Spain continued to dazzle the world, and few could see the chinks in the armour; this was an age of kings, in which bold deeds, not balance sheets, made history.

The growth of centralized monarchy claiming absolute sovereignty over its subjects may be observed in other places, from the England of Henry VIII on the extreme west of Europe to the Muscovite tsardom of Ivan III the Great on its eastern edge, for the New Monarchy was one aspect of a more general phenomenon—a great recovery that surged through Europe in the 15th century. No single cause can be adduced to explain it. Some historians believe it was simply the upturn in the natural cycle of growth: the great medieval population boom had overextended Europe's productive capacities; the depression of the 14th and early 15th centuries had corrected this condition through famines and epidemics, leading to depopulation; now the cycle of growth was beginning again.

The effects of increased food production and new technology

Once more, growing numbers of people, burgeoning cities, and ambitious governments were demanding food, goods, and services—a demand that was met by both old and new methods of production. In agriculture, the shift toward commercial crops such as wool and grains, the investment of capital, and the emancipation of servile labour completed the transformation of the manorial system already in decline. (In eastern Europe, however, the formerly free peasantry was now forced into serfdom by an alliance between the monarchy and the landed gentry, as huge agrarian estates were formed to raise grain for an expanding Western market.) Manufacturing boomed, especially of those goods used in the outfitting of armies and fleets—cloth, armour, weapons, and ships. New mining and metalworking technology made possible the profitable exploitation of the rich iron, copper, gold, and silver deposits of central Germany, Hungary, and Austria, affording the opportunity for large-scale investment of capital.

One index of Europe's recovery is the spectacular growth of certain cities. Antwerp, for example, more than doubled its population in the second half of the 15th century and doubled it again by 1560. Under Habsburg patronage, Antwerp became the chief European entrepôt for English cloth, the hub of an international banking network, and the principal Western market for German copper and silver, Portuguese spices, and Italian alum. By 1500 the Antwerp Bourse was the central money market for much of Europe. Other cities profited from their special circumstances, too: Lisbon as the home port for the Portuguese maritime empire; Seville, the Spaniards' gateway to the New World; London, the capital of the Tudors and gathering point for England's cloth-making and banking activity; Lyon, favoured by the French kings as a market centre and capital of the silk industry; and Augsburg, the principal north-south trade route in Germany and the home city of the Fugger merchant-bankers. (For further discussion, see below *Early modern Europe: Economy and society*.)

Northern humanism. Cities were also markets for culture. The resumption of urban growth in the second half of the 15th century coincided with the diffusion of Renaissance ideas and educational values. Humanism offered linguistic and rhetorical skills that were becoming indispensable for nobles and commoners seeking careers in diplomacy and government administration, while the Renaissance ideal of the perfect gentleman was a cultural style that had great appeal in this age of growing courtly refinement. At first many who wanted a humanist education went to Italy, and many foreign names appear on the rosters of the Italian universities. By the end of the century, however, such northern cities as London, Paris, Antwerp, and Augsburg were becoming centres of humanist activity rivaling Italy's. The development of printing, by making books cheaper and more plentiful, also quickened the diffusion of humanism.

A textbook convention, heavily armoured against truth by constant reiteration, states that northern humanism—*i.e.*, humanism outside Italy—was essentially Christian in spirit and purpose, in contrast to the essentially secular nature of Italian humanism. In fact, however, the program of Christian humanism had been laid out by Italian humanists of the stamp of Lorenzo Valla, one of the founders of classical philology, who showed how the critical methods used to study the classics ought to be applied to problems of biblical exegesis and translation as well as church history. That this program only began to be carried out in the 16th century, particularly in the countries of northern Europe (and Spain), is a matter of chronology rather than of geography. In the 15th century, the necessary skills, particularly the knowledge of Greek, were possessed by a few scholars; a century later, Greek was a regular part of the humanist curriculum, and Hebrew was becoming much better known, particularly after Johannes

Christian humanism

Reuchlin published his Hebrew grammar in 1506. Here, too, printing was a crucial factor, for it made available a host of lexicographical and grammatical handbooks and allowed the establishment of normative biblical texts and the comparison of different versions of the Bible.

Christian humanism was more than a program of scholarship, however; it was fundamentally a conception of the Christian life that was grounded in the rhetorical, historical, and ethical orientation of humanism itself. That it came to the fore in the early 16th century was the result of a variety of factors, including the spiritual stresses of rapid social change and the inability of the ecclesiastical establishment to cope with the religious needs of an increasingly literate and self-confident laity. By restoring the gospel to the centre of Christian piety, the humanists believed they were better serving the needs of ordinary people. They attacked scholastic theology as an arid intellectualization of simple faith, and they deplored the tendency of religion to become a ritual practiced vicariously through a priest. They also despised the whole late-medieval apparatus of relic mongering, hagiology, indulgences, and image worship, and they ridiculed it in their writings, sometimes with devastating effect. According to the Christian humanists, the fundamental law of Christianity was the law of love as revealed by Jesus Christ in the Gospel. Love, peace, and simplicity should be the aims of the good Christian, and the life of Christ his perfect model. The chief spokesman for this point of view was Desiderius Erasmus, the most influential humanist of his day. Erasmus and his colleagues were uninterested in dogmatic differences and were early champions of religious toleration. In this they were not in tune with the changing times, for the outbreak of the Reformation polarized European society along confessional lines, with the paradoxical result that the Christian humanists, who had done so much to lay the groundwork for religious reform, ended by being suspect on both sides—by the Roman Catholics as subversives who (as it was said of Erasmus) had "laid the egg that Luther hatched" and by the Protestants as hypocrites who had abandoned the cause of reformation out of cowardice or ambition. Toleration belonged to the future, after the killing in the name of Christ sickened and passions had cooled.

Christian mystics. The quickening of the religious impulse that gave rise to Christian humanism was also manifested in a variety of forms of religious devotion among the laity, including mysticism. In the 14th century a wave of mystical ardour seemed to course down the valley of the Rhine, enveloping men and women in the rapture of intense, direct experience of the divine Spirit. It centred in the houses of the Dominican order, where friars and nuns practiced the mystical way of their great teacher, Meister Eckhart. This wave of Rhenish mysticism radiated beyond convent walls to the marketplaces and hearths of the laity. Eckhart had the gift of making his abstruse doctrines understandable to a wider public than was usual for mystics; moreover, he was fortunate in having some disciples of a genius almost equal to his own—the great preacher of practical piety, Johann Tauler, and Heinrich Suso, whose devotional books, such as *The Little Book of Truth* and *The Little Book of Eternal Wisdom,* reached eager lay readers hungry for spiritual consolation and religious excitement. Some found it by joining the Dominicans; others, remaining in the everyday world, joined with like-spirited brothers and sisters in groups known collectively as the Friends of God, where they practiced methodical contemplation, or, as it was widely known, mental prayer. Probably few reached, or even hoped to reach, the ecstasy of mystical union, which was limited to those with the appropriate psychological or spiritual gifts. Out of these circles came the anonymous *German Theology,* from which, Luther was to say, he had learned more about man and God than from any book except the Bible and the writings of St. Augustine.

Spread of mysticism

In the Netherlands the mystical impulse awakened chiefly under the stimulus of another great teacher, Gerhard Groote. Not a monk nor even a priest, Groote gave the mystical movement a different direction by teaching that true spiritual communion must be combined with moral action, for this was the whole lesson of the Gospel. At his death a group of followers formed the Brethren of the Common Life. These were laymen and laywomen, married and single, earning their livings in the world but united by a simple rule that required them to pool their earnings and devote themselves to spiritual works, teaching, and charity. Houses of Brothers and Sisters of the Common Life spread through the cities and towns of the Netherlands and Germany, and a monastic counterpart was founded in the order of Canons Regular of St. Augustine, known as the Windesheim Congregation, which in the second half of the 15th century numbered some 82 priories. The Brethren were particularly successful as schoolmasters, combining some of the new linguistic methods of the humanists with a strong emphasis upon Bible study. Among the generations of children who absorbed the new piety (*devotio moderna*) in their schools were Erasmus and, briefly, Luther. In the ambience of the *devotio moderna* appeared one of the most influential books of piety ever written, *The Imitation of Christ,* attributed to Thomas à Kempis, a monk of the Windesheim Congregation.

The *devotio moderna*

Bibliotheque municipale de Valenciennes, France



Detail of an illustration from the *Sermons on the Passion* (MS 230), showing the French theologian Jean de Gerson preaching to the congregation on the devotional work *The Imitation of Christ,* by Thomas à Kempis. In the Bibliothèque municipale, Valenciennes, Fr.

One man whose life was changed by *The Imitation* was the 16th-century Spaniard Ignatius of Loyola. After reading it, Loyola founded the Society of Jesus and wrote his own book of methodical prayer, *Spiritual Exercises.* Thus, Spanish piety was in some ways connected with that of the Netherlands; but the extraordinary outburst of mystical and contemplative activity in 16th-century Spain was mainly an expression of the intense religious exaltation of the Spanish people themselves as they confronted the tasks of reform, Counter-Reformation, and world leadership. Spanish mysticism belies the usual picture of the mystic as a withdrawn contemplative, with his or her head in the clouds. Not only Loyola but also St. Teresa of Avila and her disciple, St. John of the Cross, were tough, activist Reformers who regarded their mystical experiences as means of fortifying themselves for their practical tasks. They were also prolific writers who could communicate their experiences and analyze them for the benefit of others. This is especially true of St. John of the Cross, whose mystical poetry is one of the glories of Spanish literature.

The growth of vernacular literature. In literature, medieval forms continued to dominate the artistic imagination throughout the 15th century. Besides the vast devotional literature of the period—the *ars moriendi,* or books on the art of dying well, the saints' lives, and manuals of methodical prayer and spiritual consolation—the most popular reading of noble and burgher alike was a 13th-century love allegory, the *Roman de le rose.* Despite a promising start in the late Middle Ages, literary creativity suffered from the domination of Latin as the language of "serious" expression, with the result that, if the vernacular attracted writers, they tended to overload it with Latinisms

and artificially applied rhetorical forms. This was the case with the so-called *grande rhetoriqueurs* of Burgundy and France. One exception is 14th-century England, where a national literature made a brilliant showing in the works of William Langland, John Gower, and, above all, Geoffrey Chaucer. The troubled 15th century, however, produced only feeble imitations. Another exception is the vigorous tradition of chronicle writing in French, distinguished by such eminently readable works as the chronicle of Jean Froissart and the memoirs of Philippe de Commynes. In France, too, about the middle of the 15th century there lived the vagabond François Villon, a great poet about whom next to nothing is known. In Germany *The Ship of Fools,* by Sebastian Brant, was a lone masterpiece.

Renaissance of national literatures

The 16th century saw a true renaissance of national literatures. In Protestant countries, the Reformation had an enormous impact upon the quantity and quality of literary output. If Luther's rebellion destroyed the chances of unifying the nation politically, his translation of the Bible into German created a national language. Biblical translations, vernacular liturgies, hymns, and sacred drama had analogous effects elsewhere. For Roman Catholics, especially in Spain, the Reformation was a time of deep religious emotion expressed in art and literature. On all sides of the religious controversy, chroniclers and historians writing in the vernacular were recording their versions for posterity.

While the Reformation was providing a subject matter, the Italian Renaissance was providing literary methods and models. The Petrarchan sonnet inspired French, English, and Spanish poets, while the Renaissance neoclassical drama finally began to end the reign of the medieval mystery play. Ultimately, of course, the works of real genius were the result of a crossing of native traditions and new forms. The Frenchman François Rabelais assimilated all the themes of his day—and mocked them all—in his story of the giants Gargantua and Pantagruel. The Spaniard Miguel de Cervantes, in *Don Quixote,* drew a composite portrait of his countrymen, which caught their exact mixture of idealism and realism. In England, Christopher Marlowe and William Shakespeare used Renaissance drama to probe the deeper levels of their countrymen's character and experiences.

RENAISSANCE SCIENCE AND TECHNOLOGY

According to medieval scientists, matter was composed of four elements—earth, air, fire, and water—whose combinations and permutations made up the world of visible objects. The cosmos was a series of concentric spheres in motion, the farther ones carrying the stars around in their daily courses. At the centre was the globe of Earth, heavy and static. Motion was either perfectly circular, as in the heavens, or irregular and naturally downward, as on Earth. The Earth had three landmasses—Europe, Asia, and Africa—and was unknown and uninhabitable in its southern zones. Human beings, the object of all creation, were composed of four humours—black and yellow bile, blood, and phlegm—and the body's health was determined by the relative proportions of each. The cosmos was alive with a universal consciousness with which people could interact in various ways, and the heavenly bodies were generally believed to influence human character and events, although theologians worried about free will.

New concepts of natural phenomena

These views were an amalgam of classical and Christian thought and, from what can be inferred from written sources, shaped the way educated people experienced and interpreted phenomena. What people who did not read or write books understood about nature is more difficult to tell, except that belief in magic, good and evil spirits, witchcraft, and forecasting the future was universal. The church might prefer that Christians seek their well-being through faith, the sacraments, and the intercession of Mary and the saints, but distinctions between acceptable and unacceptable belief in hidden powers were difficult to make or to maintain. Most clergy shared the common beliefs in occult forces and lent their authority to them. The collaboration of formal doctrine and popular belief had some of its most terrible consequences during the Renaissance, such as pogroms against Jews and witch-hunts, in which the church provided the doctrines of Satanic conspiracy and the inquisitorial agents and popular prejudice supplied the victims, predominantly women and marginal people.

Among the formally educated, if not among the general population, traditional science was transformed by the new heliocentric, mechanistic, and mathematical conceptions of Copernicus, Harvey, Kepler, Galileo, and Newton. Historians of science are increasingly reluctant to describe these changes as a revolution, since this implies too sudden and complete an overthrow of the earlier model. Aristotle's authority gave way very slowly, and only the first of the great scientists mentioned above did his work in the period under consideration. Still, the Renaissance made some important contributions toward the process of paradigm shift, as the 20th-century historian of science Thomas Kuhn called major innovations in science. Humanist scholarship provided both originals and translations of ancient Greek scientific works—which enormously increased the fund of knowledge in physics, astronomy, medicine, botany, and other disciplines—and presented as well alternative theories to those of Ptolemy and Aristotle. Thus, the revival of ancient science brought heliocentric astronomy to the fore again after almost two millennia. Renaissance philosophers, most notably Jacopo Zabarella, analyzed and formulated the rules of the deductive and inductive methods by which scientists worked, while certain ancient philosophies enriched the ways in which scientists conceived of phenomena. Pythagoreanism, for example, conveyed a vision of a harmonious geometric universe that helped form the mind of Copernicus.

In mathematics the Renaissance made its greatest contribution to the rise of modern science. Humanists included arithmetic and geometry in the liberal arts curriculum; artists furthered the geometrization of space in their work on perspective; Leonardo da Vinci perceived, however faintly, that the world was ruled by "number." The interest in algebra in the Renaissance universities, according to the 20th-century historian of science George Sarton, "was creating a kind of fever." It produced some mathematical theorists of the first rank, including Niccolò Tartaglia and Girolamo Cardano. If they had done nothing else, Renaissance scholars would have made a great contribution to mathematics by translating and publishing, in 1544, some previously unknown works of Archimedes, perhaps the most important of the ancients in this field.

If the Renaissance role in the rise of modern science was more that of midwife than of parent, in the realm of technology the proper image is the Renaissance magus, manipulator of the hidden forces of nature. Working with medieval perceptions of natural processes, engineers and technicians of the 15th and 16th centuries achieved remarkable results and pushed the traditional cosmology to the limit of its explanatory powers. This may have had more to do with changing social needs than with changes in scientific theory. Warfare was one catalyst of practical change that stimulated new theoretical questions. With the spread of the use of artillery, for example, questions about the motion of bodies in space became more insistent, and mathematical calculation more critical. The manufacture of guns also stimulated metallurgy and fortification; town planning and reforms in the standards of measurement were related to problems of geometry. The Renaissance preoccupation with alchemy, the parent of chemistry, was certainly stimulated by the shortage of precious metals, made more acute by the expansion of government and expenditures on war.

Development of printing

The most important technological advance of all, because it underlay progress in so many other fields, strictly speaking, had little to do with nature. This was the development of printing, with movable metal type, about the mid-15th century in Germany. Johannes Gutenberg is usually called its inventor, but in fact many people and many steps were involved. Block printing on wood came to the West from China between 1250 and 1350, papermaking came from China by way of the Arabs to 12th-century Spain, whereas the Flemish technique of oil painting was the origin of the new printers' ink. Three men of Mainz—Gutenberg and his contemporaries Johann Fust and Peter Schöffer—seem to have taken the final steps, casting metal type and

locking it into a wooden press. The invention spread like the wind, reaching Italy by 1467, Hungary and Poland in the 1470s, and Scandinavia by 1483. By 1500 the presses of Europe had produced some six million books. Without the printing press it is impossible to conceive that the Reformation would have ever been more than a monkish quarrel or that the rise of a new science, which was a cooperative effort of an international community, would have occurred at all. In short, the development of printing amounted to a communications revolution of the order of the invention of writing; and, like that prehistoric discovery, it transformed the conditions of life. The communications revolution immeasurably enhanced human opportunities for enlightenment and pleasure on one hand and created previously undreamed-of possibilities for manipulation and control on the other. The consideration of such contradictory effects may guard us against a ready acceptance of triumphalist conceptions of the Renaissance or of historical change in general. (D.We.)

The emergence of modern Europe, 1500–1648

ECONOMY AND SOCIETY

The 16th century was a period of vigorous economic expansion. This expansion in turn played a major role in the many other transformations—social, political, and cultural—of the early modern age.

By 1500 the population in most areas of Europe was increasing after two centuries of decline or stagnation. The bonds of commerce within Europe tightened, and the "wheels of commerce" (in the phrase of the 20th-century French historian Fernand Braudel) spun ever faster. The great geographic discoveries then in process were integrating Europe into a world economic system. New commodities, many of them imported from recently discovered lands, enriched material life. Not only trade but also the production of goods increased as a result of new ways of organizing production. Merchants, entrepreneurs, and bankers accumulated and manipulated capital in unprecedented volume. Most historians locate in the 16th century the beginning, or at least the maturing, of Western capitalism. Capital assumed a major role not only in economic organization but also in political life and international relations. Culturally, new values—many of them associated with the Renaissance and Reformation—diffused through Europe and changed the ways in which people acted and the perspectives by which they viewed themselves and the world.

The birth of Western capitalism

This world of early capitalism, however, can hardly be regarded as stable or uniformly prosperous. Financial crashes were common; the Spanish crown, the heaviest borrower in Europe, suffered repeated bankruptcies (in 1557, 1575–77, 1596, 1607, 1627, and 1647). The poor and destitute in society became, if not more numerous, at least more visible. Even as capitalism advanced in the West, the once-free peasants of central and eastern Europe slipped into serfdom. The apparent prosperity of the 16th century gave way in the middle and late periods of the 17th century to a "general crisis" in many European regions. Politically, the new centralized states insisted on new levels of cultural conformity on the part of their subjects. Several states expelled Jews, and almost all of them refused to tolerate religious dissenters. Culturally, in spite of the revival of ancient learning and the reform of the churches, a hysterical fear of witches grasped large segments of the population, including the learned. Understandably, historians have had difficulty defining the exact place of this complex century in the course of European development.

The economic background. The century's economic expansion owed much to powerful changes that were already under way by 1500. At that time, Europe comprised only between one-third and one-half the population it had possessed about 1300. The infamous Black Death of 1347–50 principally accounts for the huge losses, but plagues were recurrent, famines frequent, wars incessant, and social tensions high as the Middle Ages ended. The late medieval disasters radically transformed the structures of European society—the ways by which it produced food and goods, distributed income, organized its society and state, and looked at the world.

The huge human losses altered the old balances among the classical "factors of production"—labour, land, and capital. The fall in population forced up wages in the towns and depressed rents in the countryside, as the fewer workers remaining could command a higher "scarcity value." In contrast, the costs of land and capital fell; both grew relatively more abundant and cheaper as human numbers shrank. Expensive labour and cheap land and capital encouraged "factor substitution," the replacement of the costly factor (labour) by the cheaper ones (land and capital). This substitution of land and capital for labour can be seen, for example, in the widespread conversions of arable land to pastures; a few shepherds, supplied with capital (sheep) and extensive pastures, could generate a higher return than plowland, intensively farmed by many well-paid labourers.

Capital could also support the technology required to develop new tools, enabling labourers to work more productively. The late Middle Ages was accordingly a period of significant technological advances linked with high capital investment in labour-saving devices. The development of printing by movable metal type substituted an expensive machine, the press, for many human copyists. Gunpowder and firearms gave smaller armies greater fighting power. Changes in shipbuilding and in the development of navigational aids allowed bigger ships to sail with smaller crews over longer distances. By 1500 Europe achieved what it had never possessed before: a technological edge over all other civilizations. Europe was thus equipped for worldwide expansion.

Europe's technological edge

Social changes also were pervasive. With a falling population, the cost of basic foodstuffs (notably wheat) declined. With cheaper food, people in both countryside and city could use their higher earnings to diversify and improve their diets—to consume more meat, dairy products, and beverages. They also could afford more manufactured products from the towns, to the benefit of the urban economies. The 14th century is rightly regarded as the golden age of working people.

Economic historians have traditionally envisioned the falling costs of the basic foodstuffs (cereals) and the continuing firm price of manufactures as two blades of a pair of open scissors. These price scissors diverted income from countryside to town. The late medieval price movements thus favoured urban artisans over peasants and merchants over landlords. Towns achieved a new weight in society; the number of towns counting more than 10,000 inhabitants increased from 125 in about 1300 to 154 in 1500, even as the total population was dropping. These changes undermined the leadership of the landholding nobility and enhanced the power and influence of the great merchants and bankers of the cities. The 16th would be a "bourgeois century."

Culturally, the disasters of the late Middle Ages had the effect of altering attitudes and in particular of undermining the medieval faith that speculative reason could master the secrets of the universe. In an age of ferocious and unpredictable epidemics, the accidental and the unexpected, chance or fate, rather than immutable laws, seemed to dominate the course of human affairs. In an uncertain world, the surest, safest philosophical stance was empiricism. In formal philosophy, this new priority given to the concrete and the observable over and against the abstract and the speculative was known as nominalism. In social life, there was evident a novel emphasis on close observation, on the need to study each changing situation to arrive at a basis for action.

The 16th century thus owed much to trends originating in the late Middle Ages. It would, however, be wrong to view its history simply as a playing out of earlier movements. New developments proper to the century also shaped its achievements. Those developments affected population; money and prices; agriculture, trade, manufacturing, and banking; social and political institutions; and cultural attitudes. Historians differ widely in the manner in which they structure and relate these various developments; they argue over what should be regarded as causes and what

as effects. But they are reasonably agreed concerning the general nature of these trends.

Demographics. For the continent as a whole, the population growth under way by 1500 continued over the "long" 16th century until the second or third decade of the 17th century. A recent estimate by the American historian Jan De Vries set Europe's population (excluding Russia and the Ottoman Empire) at 61.6 million in 1500, 70.2 million in 1550, and 78.0 million in 1600; it then lapsed back to 74.6 million in 1650. The distribution of population across the continent was also shifting. Northwestern Europe (especially the Low Countries and the British Isles) witnessed the most vigorous expansion; England's population more than doubled between 1500, when it stood at an estimated 2.6 million, and 1650, when it probably attained 5.6 million. Northwestern Europe also largely escaped the demographic downturn of the mid-17th century, which was especially pronounced in Germany, Italy, and Spain. In Germany, the Thirty Years' War (1618–48) may have cost the country, according to different estimates, between 25 and 40 percent of its population.

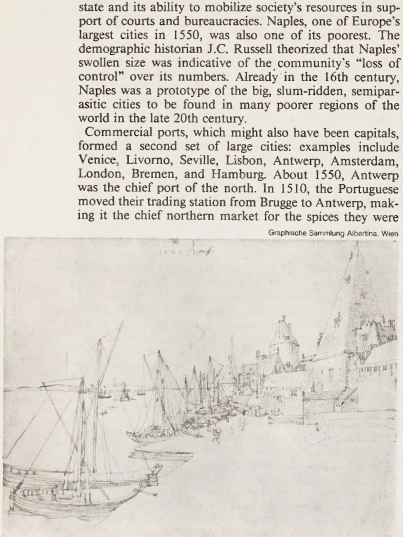
Urbanization

Cities also grew, though slowly at first. The proportion of Europeans living in cities with 10,000 or more residents increased from 5.6 percent of the total population in 1500 to only 6.3 percent in 1550. The towns of England continued to suffer a kind of depression, now often called "urban decay," in the first half of the century. The process of urbanization then accelerated, placing 7.6 percent of the population in cities by 1600, and even continued during the 17th-century crisis. The proportion of population in cities of more than 10,000 inhabitants reached 8.3 percent in 1650.

More remarkable than the slow growth in the number of urban residents was the formation of cities of a size never achieved in the medieval period. These large cities were of two principal types. Capitals and administrative centres—such as Naples, Rome, Madrid, Paris, Vienna, and Moscow—give testimony to the new powers of the state and its ability to mobilize society's resources in support of courts and bureaucracies. Naples, one of Europe's largest cities in 1550, was also one of its poorest. The demographic historian J.C. Russell theorized that Naples' swollen size was indicative of the community's "loss of control" over its numbers. Already in the 16th century, Naples was a prototype of the big, slum-ridden, semiparasitic cities to be found in many poorer regions of the world in the late 20th century.

Commercial ports, which might also have been capitals, formed a second set of large cities: examples include Venice, Livorno, Seville, Lisbon, Antwerp, Amsterdam, London, Bremen, and Hamburg. About 1550, Antwerp was the chief port of the north. In 1510, the Portuguese moved their trading station from Brugge to Antwerp, making it the chief northern market for the spices they were importing from India. The Antwerp bourse, or exchange, simultaneously became the leading money market of the north. At its heyday in mid-century, the city counted 90,000 inhabitants. The revolt of the Low Countries against Spanish rule (from 1568) ruined Antwerp's prosperity. Amsterdam, which replaced it as the greatest northern port, grew from 30,000 in 1550 to 65,000 in 1600 and 175,000 in 1650. The mid-17th century—a period of recession in many European regions—was Holland's golden age. Late in the century, Amsterdam faced the growing challenge of another northern port, which was also the capital of a powerful national state—London. With 400,000 residents by 1650 and growing rapidly, London then ranked below only Paris (440,000) as Europe's largest city. Urban concentrations of such magnitude were unprecedented; in the Middle Ages, the largest size attained was roughly 220,000, reached by a single city, Paris, about 1328.

Graphische Sammlung Albertina, Wien



"Harbour of Antwerp near the Scheldt Gate," by Albrecht Dürer, 1520. Pen and ink. In the Albertina, Vienna.

The appearance of urban systems

Another novelty of the 16th century was the appearance of urban systems, or hierarchies of cities linked together by their political or commercial functions. Most European cities had been founded in medieval or even in ancient times, but they long remained intensely competitive, duplicated each other's functions, and never coalesced during the Middle Ages into tight urban systems. The more intensive, more far-flung commerce of the early modern age required a clearer distribution of functions and cooperation as much as competition. The centralization of governments in the 16th century also demanded clearly defined lines of authority and firm divisions of functions between national and regional capitals.

Trade and the "Atlantic revolution." The new importance of northwestern Europe in terms of overall population and concentration of large cities reflects in part the "Atlantic revolution," the redirection of trade routes brought about by the great geographic discoveries. The Atlantic revolution, however, did not so much replace the old lines of medieval commerce as build upon them. In the Middle Ages, Italian ports—Venice and Genoa in particular—dominated trade with the Middle East and supplied Europe with Eastern wares and spices. In the north, German cities, organized into a loose federation known as the Hanseatic League, similarly dominated Baltic trade. When the Portuguese in 1498 opened direct maritime links with India, Venice faced the competition of the Atlantic ports, first Lisbon and Antwerp. Nonetheless, Venice effectively responded to the new competition and attained in the 16th century its apogee of commercial importance; in most of its surviving monuments, this beautiful city still reflects its 16th-century prosperity. Genoa was not well placed to take advantage of the Atlantic discoveries, but Genoese bankers played a central role in the finances of Spain's overseas empire and in its military ventures in Europe. Italians did not quickly relinquish the prominence as merchants and bankers that had distinguished them in the Middle Ages.

In the north, the Hanseatic towns faced intensified competition from the Dutch, who from about 1580 introduced a new ship design (the *fluitschip,* a sturdy, cheaply built cargo vessel) and new techniques of shipbuilding, including wind-powered saws. Freight charges dropped and the size of the Dutch merchant marine soared; by the mid-17th century, it probably exceeded in number of vessels all the other mercantile fleets of Europe combined. The English competed for a share in the Baltic trade, though they long remained well behind the Dutch.

In absolute terms, Baltic trade was booming. In 1497 the ships passing through the Sound separating Denmark from Sweden numbered 795; 100 years later the number registered by the toll collectors reached 6,673. The percentage represented by Hanseatic ships rose over the same century from roughly 20 to 23–25 percent; the Germans were not yet routed from these eastern waters.

In terms of maritime trade, the Atlantic revolution may well have stimulated rather than injured the older exchanges. At the same time, new competition from the western ports left both Hanseatics and Italians vulnerable to the economic downturn of the 17th century. For both the Hanseatic and Italian cities, the 17th—and not the 16th—century was the age of decline. At Lübeck in

1628, at the last meeting of the Hanseatic towns, only 11 cities were represented, and later attempts to call a general meeting ended in failure.

Prices and inflation. In historical accounts, the glamour of the overseas discoveries tends to overshadow the intensification of exchanges within the continent. Intensified exchanges led to the formation of large integrated markets for at least some commodities. Differences in the price of wheat in the various European regions leveled out as the century progressed, and prices everywhere tended to fluctuate in the same direction. The similar price movements over large areas mark the emergence of a single integrated market in cereals. Certain regions came to specialize in wheat production and to sell their harvests to distant consumers. In particular, the lands of the Vistula basin, southern Poland, and Ruthenia (western Ukraine) became regular suppliers of grain to Flanders, Holland, western Germany, and, in years of poor harvests, even England and Spain. In times of famine, Italian states also imported cereals from the far-off Baltic breadbasket. From about 1520, Hungary emerged as a principal supplier of livestock to Austria, southern Germany, and northern Italy.

Changes in price levels in the 16th century profoundly affected every economic sector, but in ways that are disputed. The period witnessed a general inflation, known traditionally as the "price revolution." It was rooted in part in frequent monetary debasements; the French kings, for example, debased or altered their chief coinage, the *livre tournois,* in 1519, 1532, 1549, 1561, 1571–75 (four mutations), and 1577. Probably more significant (though even this is questioned) was the infusion of new stocks of precious metal, especially silver, into the money supply. The medieval economy had suffered from a chronic shortage of precious metals. From the late 15th century, however, silver output, especially from German mines, increased and remained high through the 1530s. New techniques of sinking and draining shafts, extracting ore, and refining silver made mining a booming industry. From 1550 "American treasure," chiefly from the great silver mine at Potosí in Peru (now in Bolivia), arrived in huge volumes in Spain, and from Spain it flowed to the many European regions where Spain had significant military or political engagements. Experts estimate (albeit on shaky grounds) that the stock of monetized silver increased by three or three and a half times during the 16th century.

The price revolution

At the same time, the growing numbers of people who had to be fed, clothed, and housed assured that coins would circulate rapidly. In monetary theory, the level of prices varies directly with the volume of money and the velocity of its circulation. New sources of silver and new numbers of people thus launched (or at least reinforced) pervasive inflation. According to one calculation, prices rose during the century in nominal terms by a factor of six and in real terms by a factor of three. The rate is low by modern standards, but it struck a society accustomed to stability. As early as 1568 the French political theorist Jean Bodin perceptively attributed the inflation to the growing volume of circulating coin, but many others, especially those victimized by inflation, chose to blame it on the greed of monopolists. Inflation contributed no small part to the period's social tensions.

Inflation always redistributes wealth; it penalizes creditors and those who live on fixed rents or revenues; it rewards debtors and entrepreneurs who can take immediate advantage of rising prices. Moreover, prices tend to rise faster than wages. For the employer, costs (chiefly wages) lag behind receipts (set by prices), and this forms what is classically known as "profit inflation." This profit inflation has attracted the interest of economists as well as historians; especially notable among the former is the great British economic theorist John Maynard Keynes. In a treatise on money published in 1930, he attributed to the 16th-century price revolution and profit inflation a crucial role in the primitive accumulation of capital and in the birth of capitalism itself. His analysis has attracted much criticism. Wages lagged not so much behind the prices of manufactured goods as of agricultural commodities, and inflation may not have increased profits at all. Then, too, inflation in Spain (particularly pronounced in the 1520s), or later in France, did not lead to a burst of enterprise. There is no mechanical connection between price structures and behaviour.

On the other hand, the price revolution certainly stimulated the economy. It clearly penalized the inactive. Those who wished to do no more than maintain their traditional standard of living had, nonetheless, to assume an active economic stance. The increased supply of money seems further to have lowered interest rates—another advantage for the entrepreneur. The price revolution by itself did not assure capital accumulation and the birth of capitalism, but it did bring about increased outlays of entrepreneurial energy.

The Bettmann Archive



Engraving showing coins being minted, from *The New Art of Coinage,* 16th century.

Landlords and peasants. The growing population in the 16th century and the larger concentrations of urban dwellers required abundant supplies of food. In the course of the century, wheat prices steadily rose; the blades of late medieval price scissors once more converged. Money again flowed into the countryside to pay for food, especially wheat. But the social repercussions of the rising price of wheat varied in the different European regions.

In eastern Germany (with the exception of electoral Saxony), Poland, Bohemia, Hungary, Lithuania, and even eventually Russia, the crucial change was the formation of a new type of great property, called traditionally in the German literature the *Gutsherrschaft* (ownership of an estate). The estate was divided into two principal parts: the landlord's demesne, from which he took all the harvest; and the farms of the peasants, who supplied the labour needed to work the demesne. The peasants (and their children after them) were legally serfs, bound to the soil. These bipartite, serf-run estates superficially resemble the classical manors of the early Middle Ages but differ from them in that the new estates were producing primarily for commercial markets. The binding of the peasants of eastern Europe to the soil and the imposition of heavy labour services constitute, in another traditional term, the "second serfdom."

Gutsherrschaft and *Grundherrschaft*

In the contemporary west (and in the east before the 16th century), the characteristic form of great property was the *Grundherrschaft* ("ownership of land"). This was an aggregation of rent-paying properties. The lord might also be a cultivator, but he worked his land through hired labourers.

What explains the formation of the *Gutsherrschaft* in early modern eastern Europe? Historians distinguish two phases in its appearance. The nobility and gentry, even

without planning to do so, accumulated large tracts of abandoned land during the late medieval population collapse. However, depopulation also meant that landlords could not easily find the labour to work their extensive holdings. Population, as previously mentioned, was growing again by 1500, and prices (especially the price of cereals) steadily advanced. Inflation threatened the standard of living of the landlords; to counter its effects, they needed to raise their incomes. They accordingly sought to win larger harvests from their lands, but the lingering shortage of labourers was a major obstacle. As competition for their labour remained high, peasants were prone to move from one estate to another, in search of better terms. Moreover, the landlords had little capital to hire salaried hands and, in the largely rural east, there were few sources of capital. They had, however, one recourse. They dominated the weak governments of the region, and even a comparatively strong ruler, like the Russian tsar, wished to accommodate the demands of the gentry. In 1497 the Polish gentry won the right to export their grain without paying duty. Further legislation bound the peasants to the soil and obligated them to work the lord's demesne. The second serfdom gradually spread over eastern Europe; it was established in Poland as early as 1520; in Russia it was legally imposed in the Ulozhenie (Law Code) of 1649. At least in Poland, the western market for cereals was a principal factor in reviving serfdom, in bringing back a seemingly primitive form of labour organization.

No second serfdom developed in western Europe, even though the stimulus of high wheat prices was equally powerful. Harassed landlords, pressed to raise their revenues, had more options than their eastern counterparts. They might look to a profession or even a trade or, more commonly, seek at court an appointment paying a salary or a pension. The western princes did not want local magnates to dominate their communities, as this would erode their own authority. They consequently defended the peasants against the encroachments of the gentry. Finally, landlords in the west could readily find capital. They could use the money either to hire workers or to improve their leased properties, in expectation of gaining higher rents. The availability of capital in the west and its scarcity in the east were probably the chief reasons why the agrarian institutions of eastern and western Europe diverged so dramatically in the 16th century.

In the west, in areas of plow agriculture, the small property remained the most common productive unit. However, the terms under which it was held and worked differed widely from one European region to another. In the Middle Ages, peasants were typically subject to a great variety of charges laid upon both their persons and the land. They had to pay special marriage and inheritance taxes; they were further required to provide tithes to the parish churches. These charges were often small—sometimes only recognitive—and were fixed by custom. They are often regarded as "feudal" as distinct from "capitalist" rents, in that they were customary and not negotiated; the lord, moreover, provided nothing—no help or capital improvements—in return for the payments.

Conversion from feudal to capitalist rent systems

The 16th century witnessed a conversion—widespread though never complete—from systems of feudal to capitalist rents. The late medieval population collapse increased the mobility of the peasant population; a peasant who settled for one year and one day in a "free village" or town received perpetual immunity from personal charges. Personal dues thus eroded rapidly; dues weighing upon the land persisted longer but could not be raised. It was therefore in the landlord's interest to convert feudal tenures into leaseholds, and this required capital.

In England upon the former manors, farmers (the original meaning of the term was leaseholder or rent payer), who held land under long-term leases, gradually replaced copyholders, or tenants subject only to feudal dues. These farmers constituted the free English yeomanry, and their appearance marks the demise of the last vestiges of medieval serfdom. In the Low Countries, urban investors bought up the valuable lands near towns and converted them into leaseholds, which were leased for high rents over long terms. The heavy infusions of urban capital into Low Country agriculture helped make it technically the most advanced in Europe, a model for improving landlords elsewhere. In central and southern France and in central Italy, urban investment in the land was closely linked to a special type of sharecropping lease, called the *métayage* in France and the *mezzadria* in Italy. The landlord (typically a wealthy townsman) purchased plots, consolidated them into a farm, built a house upon it, and rented it. Often, he also provided the implements needed to work the land, livestock, and fertilizer. The tenant gave as rent half of the harvest. The spread of this type of sharecropping in the vicinity of towns had begun in the late Middle Ages and was carried vigorously forward in the 16th century. Nonetheless, the older forms of feudal tenure, and even some personal charges, also persisted, especially in Europe's remote and poorer regions. The early modern countryside presents an infinitely complex mixture of old and new ways of holding and working the land.

Two further changes in the countryside are worth noting. In adopting Protestantism, the North German states, Holland, the Scandinavian countries, and England confiscated and sold, in whole or in part, ecclesiastical properties. Sweden, for example, did so in 1526–27, England in 1534–36. It is difficult to assess the exact economic repercussions of these secularizations, but the placing of numerous properties upon the land market almost surely encouraged the infusion of capital into (and the spread of capitalist forms of agrarian organization in) the countryside.

Second, the high price of wheat did not everywhere make cereal cultivation the most remunerative use of the land. The price of wool continued to be buoyant, and this, linked with the availability of cheap wheat from the east, sustained the conversion of plowland into pastures that also had begun in the late Middle Ages. In England this movement is called "enclosure." In the typical medieval village, peasants held the cultivated soil in unfenced strips, and they also enjoyed the right of grazing a set number of animals upon the village commons. Enclosure meant both the consolidating of the strips into fenced fields and the division of the commons among the individual villagers. As poorer villagers often received plots too small to work, they often had little choice but to sell their share to their richer neighbours and leave the village. In 16th-century England, enclosure almost always meant the conversion of plowland and commons into fenced meadows or pastures. To many outspoken observers, clergy and humanists in particular, enclosures were destroying villages, uprooting the rural population, and multiplying beggars on the road and paupers in the towns. Sheep were devouring the people—"Where there have been many householders and inhabitants," the English bishop Hugh Latimer lamented, "there is now but a shepherd and his dog." In light of recent research, these 16th-century enclosures were far less extensive than such strictures imply. Nonetheless, enclosures are an example of the power of capital to transform the rhythms of everyday life; at the least, they were an omen of things to come.

Enclosure

In Spain, sheep and people also entered into destructive competition. Since the 13th century, sheepherding had fallen under the control of a guild known as the Mesta; the guild was in turn dominated by a few grandees. The Mesta practiced transhumance (alternation of winter and spring pastures); the flocks themselves moved seasonally along great trailways called *cañadas*. The government, which collected a tax on exported wool, was anxious to raise output and favoured the Mesta with many privileges. Cultivators along the *cañadas* were forbidden to fence their fields, lest the barriers impede the migrating sheep. Moreover, the government imposed ceiling prices on wheat in 1539. Damage from the flocks and the low price of wheat eventually crippled cereal cultivation, provoked widespread desertion of the countryside and overall population decline, and was a significant factor in Spain's 17th-century decline. High cereal prices primarily benefited not the peasants but the landlords. The landlords in turn spent their increased revenues on the amenities and luxuries supplied by towns. In spite of high food costs, town economies fared well.

Protoindustrialization. Historians favour the term "pro-

toindustrialization" to describe the form of industrial organization that emerged in the 16th century. The word was initially applied to cottage industries in the countryside. In spite of the opposition of urban guilds, rural residents were performing many industrial tasks. Agricultural labour did not occupy the peasants during the entire year, and they devoted their free hours to such activities as spinning wool or weaving and washing cloth. Peasants usually worked for lower remuneration than urban artisans. Protoindustrialization gave rural residents supplementary income, which conferred a certain immunity from harvest failures; it enabled them to marry younger and rear larger families; it prepared them, socially and psychologically, for eventual industrialization. The efforts of urban guilds to limit rural work enjoyed only limited success; in England, for example, the restrictions seem rarely to have been enforced. Cottage industries certainly existed in the Middle Ages, but the economic expansion of the 16th century diffused them over much larger areas of the European countryside, perhaps most visibly in England and western Germany.

More recently, historians have stressed the role of towns in this early form of industrial organization. Towns remained the centres from which the raw materials were distributed in the countryside. Moreover, urban entrepreneurs coordinated the efforts of the rural workers and marketed their finished products. Certain processes—usually the most highly skilled and the most remunerative—remained centred in cities. Not only the extension of industry into rural areas but also the greater integration of city and countryside in regional economies was the principal achievement of 16th-century industry.

The putting-out system

This manner of organizing manufactures is known as the "putting-out system," an awkward translation of the German *Verlagssystem*. The key to its operation was the entrepreneur, who purchased the raw materials, distributed them among the working families, passed the semifinished products from one artisan to another, and marketed the finished products. He was typically a great merchant resident in the town. As trade routes grew longer, the small artisan was placed at ever-greater distances from sources of supply and from markets. Typically, the small artisan would not have the knowledge of distant markets or of the preferences of distant purchasers and rarely had the money to purchase needed raw materials. The size of the trading networks and the volume of merchandise moving within them made the services of the entrepreneur indispensable and subordinated the workers to his authority.

The production of fabric remained everywhere the chief European industry, but two developments, both of them continuations of medieval changes, are noteworthy. In southern Europe the making of silk cloth, stimulated by the luxurious tastes of the age, gained unprecedented prominence. Lucca, Bologna, and Venice in Italy and Seville and Granada in Spain gained flourishing industries. Even more spectacular in its rise as a centre of silk manufacture was the city and region of Lyon in central France. Lyon was also a principal fair town, where goods of northern and southern Europe were exchanged. It was ideally placed to obtain silk cocoons or thread from the south and to market the finished cloth to northern purchasers. The silk industry is also notable in that most of the workers it employed were women.

Northern industry continued to concentrate on woolens but partially turned its efforts to producing a new type of cloth, worsteds. Unlike woolens, worsteds were woven from yarn spun from long-haired wool; moreover, the cloth is not fulled (that is, washed, mixed with fuller's earth, and pounded in order to mat the weave). Worsteds were lighter and cheaper to make than woolens and did not require the services of a mill, which might have to be located near running water. Under the name of "new draperies," worsteds had come to dominate the Flemish wool industry in the late Middle Ages. In the 16th century, several factors—the growth of population and of markets, the revolt of the Low Countries against Spain, and religious persecutions, which led many skilled Protestant workers to seek refuge among their coreligionists—stimulated the worsted industry in England. England had developed a vigorous woolens industry in the late Middle Ages, and the spread of worsted manufacture made it a European leader in fabric production.

Another major innovation in 16th-century industrial history was the growing use of coal as fuel. England, with rich coal mines located close to the sea, could take particular advantage of this cheap mineral fuel. The port of Newcastle in Northumbria emerged in the 16th century as a principal supplier of coal to London consumers. As yet, coal could not be used for the direct smelting of iron, but it found wide application in glassmaking, brick baking, brewing, and the heating of homes. The use of coal eased the demand on England's rapidly diminishing forests and contributed to the growth of a coal technology that would make a crucial contribution to the later Industrial Revolution.

In industry, the 16th century was not so much an age of dramatic technological departures; rather, it witnessed the steady improvement of older technological traditions—in shipbuilding, mining and metallurgy, glassmaking, silk production, clock and instrument making, firearms, and others. Europe slowly widened its technological edge over non-European civilizations. Most economic historians further believe that protoindustrialization, and the commerce that supplied and sustained it, best explains the early accumulations of capital and the birth of a capitalist economy.

Growth of banking and finance. Perhaps the most spectacular changes in the 16th-century economy were in the fields of international banking and finance. To be sure, medieval bankers such as the Florentine Bardi and Peruzzi in the 14th century and the Medici in the 15th had operated on an international scale, but the full development of an international money market with supporting institutions awaited the 16th century. Its earliest architects were South German banking houses, from Augsburg and Nürnberg in particular, who were well situated to serve as financial intermediaries between such southern capitals as Rome (or commercial centres such as Venice) and the northern financial centre at Antwerp. Through letters of exchange drawn on the various bourses that were growing throughout Europe, these bankers were able to mobilize capital in fabulous amounts. In 1519 Jakob II Fugger the Rich of Augsburg amassed nearly two million florins for the Habsburg king of Spain, Charles I, who used the money to bribe the imperial electors (he was successfully elected Holy Roman emperor as Charles V). Money was shaping the politics of Europe.

Finances of the Spanish Habsburgs

The subsequent bankruptcies of the Spanish crown injured the German bankers; from 1580 or even earlier, the Genoese became the chief financiers of the Spanish government and empire. Through the central fair at Lyon and through letters of exchange and a complex variant known as the *asiento*, the Genoese transferred great sums from Spain to the Low Countries to pay the soldiers of the Spanish armies. In the mid-16th century, dissatisfied with Lyon, the Genoese set up a fictional fair, known as Bisenzone (Besançon), as a centre of their fiscal operations. Changing sites several times, "Bisenzone" from 1579 settled at Piacenza in Italy.

Political and cultural influences on the economy. The centralized state of the early modern age exerted a decisive influence on the development of financial institutions and in other economic sectors as well. To maintain its power both within its borders and within the international system, the state supported a large royal or princely court, a bureaucracy, and an army. It was the major purchaser of weapons and war matériel. Its authority affected class balances. Over the century's course, the prince expanded his authority to make appointments and grant pensions. His control of resources softened the divisions among classes and facilitated social mobility. Several great merchants and bankers, the Fuggers among them, eventually were ennobled. Yet, in spending huge sums on war, the early modern state may also have injured the economy. The floating debt of the French crown came close to 10 million ecus (the ecu was worth slightly less than a gold florin), that of the Spanish, 20 million. These sums probably equaled the worth of the circulating coin in the two kingdoms. Only in England did the public debt remain at relatively modest proportions, about 200,000 gold ducats.

Governments, with the exception of the English, were absorbing a huge part of the national wealth. The Spanish bankruptcies were also sure proof that Spain had insufficient resources to realize its ambitious imperial goals.

Mercantilism

The effort to control the economy in the interest of enhancing state power is the essence of the political philosophy known as mercantilism. Many of the policies of 16th-century states affecting trade, manufactures, or money can be regarded as mercantilistic, but as yet they did not represent a coherent economic theory. The true age of mercantilism postdates 1650.

Cultural changes also worked to legitimate, even to inspire, the early modern spirit of enterprise. In a famous thesis, the German sociologist Max Weber and, later, the English historian Richard Henry Tawney posited a direct link between the Protestant ethic, specifically in its Calvinist form, and the capitalist motivation. Medieval ethics had supposedly condemned the profit motive, and teachings about usury and the just price had shackled the growth of capitalist practices. Calvinism made the successful merchant God's elect. Today, this thesis appears too simple. Many movements contributed to a reassessment of the mercantile or business life, and the rival religious confessions influenced one another. Calvinism did not really view commercial success as a sign of God's favour until the 17th century, but 16th-century Roman Catholic scholastics (as the humanists before them) had come to regard the operations of the marketplace as natural; it was good for the merchant to participate in them. Martin Luther, in emphasizing that every Christian had received a calling (*Berufung*) from God, gave new dignity to all secular employments. Roman Catholics developed their own theory of the "vocation" to both secular and religious callings in what was a close imitation of the Lutheran *Berufung*.

Aspects of early modern society. To examine the psychology of merchants is to stay within a narrow social elite. Historians, in what is sometimes called "the new social history," have paid close attention to the common people of Europe and to hitherto neglected social groups—women, the nonconformists, and minorities.

The status of women

Two fundamental changes affected the status of early modern women. Women under protoindustrialization were valued domestic workers, but they also had little economic independence; the male head of the household, the father or husband, gained the chief fruits of their labour. A second change, perhaps related to the first, was the advancing age of first marriage for women. Medieval girls were very young at first marriage, barely past puberty; these young girls were given to mature grooms who were in their middle or late 20s. By the late 16th century, parish marriage registers show that brides were nearly the same age as their grooms and both were mature persons, usually in their middle 20s. This is, in effect, what demographers call the modern, western European marriage pattern. Comparatively late ages at first marriage also indicate that significant numbers of both men and women would not marry at all. Though the origins of this pattern remain obscure, it may be that families, recognizing the economic value of daughters, were anxious to retain their services as long as possible. European marriages were overwhelmingly patrilocal—that is, the bride almost always joined her husband's household. Thus, the contribution that daughters made to the household economy exerted an upward pressure on their ages of marriage. Whatever the explanation for the new marriage pattern, the near equality of ages between the marriage partners at least opened the possibility that the two would become true friends as well as spouses; this was harder to achieve when brides were young girls and their husbands mature and experienced.

In investigating what might be called the cultural underground of the early modern age, historians now take full advantage of a distinctive type of source. The established religions of Europe, both Roman Catholic and Protestant, zealously sought to assure uniformity of belief in the regions they dominated. The courts inspired by them actively pursued not only the heterodox but also witches, the insane, and anyone who maintained an unusual style of life. The special papal court known as the Inquisition operated in many (though not all) Catholic states. Its judges carefully interrogated witnesses and kept good records. These records permit rare views into the depths of early modern society. They show how widespread was the belief in magic and the practice of witchcraft and how far popular culture diverged from the officially sanctioned ideologies. The variety and strange nature of popular beliefs have convinced some historians that Christianity had never really won the minds of rural people during the Middle Ages. Only the aggressive and reformed churches of the 16th century succeeded in converting the peasants to formal Christianity. This thesis may be doubted, but it cannot be doubted that the European countryside sheltered deep wells of popular culture which the documentation of the age leaves largely in darkness.

Witchcraft presents special problems. Witches were hunted in the 16th century with a relentlessness never seen before. Were they becoming more numerous, their services more in demand? It may be that the two reformations, Protestant and Catholic, purged Europe of the magical aura that the medieval church had hung over it. It may be that the abiding thirst for enchantment could be slaked only in the cultural underground, only through popular magic. But it may also be that the new determination and efficiency of the reformed religions and the early modern states simply exposed persons long a fixture in village life: the woman healer, who knew the ancient, time-honoured cures; the old wife, who through charms or potions could induce conception or sterility, love or hate. It is hard even to reconstruct the character of early modern witchcraft. Terrorized witnesses tended to respond in ways they thought would please their interrogators; thus they reinforced stereotypes rather than revealing what they truly believed or did. Court records of this kind are not flawless sources, but they remain a rich vein of cultural history. Ironically, the court officials saved for history the thoughts and values they had hoped to extirpate.

Persecution of the Jews

The 16th century also witnessed a continuing deterioration in the status of western Jews. They had been expelled from England in 1290 and from France in 1306 (the first of several expulsions and readmissions). Riots and killings accompanying the Black Death (the Jews were accused of poisoning the wells) had pushed the centres of German Jewry (the Ashkenazim) to the east, into Poland, Lithuania, and, eventually, the Russian Empire. In 1492 the Jews of Spain (the Sephardim), who had formed the largest and most culturally accomplished western community, were given the choice of conversion or expulsion. Many chose to leave for Portugal (whence they would also be subsequently expelled), the Low Countries, Italy, or the Ottoman Empire. Those who remained and ostensibly converted were called "New Christians," or Marranos, and many of these later chose to emigrate to more hospitable lands. Many Marranos continued to live as Jews while professing Christianity; accusations against them were commonly heard by the Inquisition in both Spain and Italy. Their position was especially distressing. Often, both Jews and Christians rejected them, the former for their ostensible conversion, the latter for secretly practicing Judaism.

The communities of exiles had different experiences. Jews in Holland made a major contribution to the country's great prosperity. The Italian states, papal Rome included, accepted the exiles, hoping to profit from their commercial and financial expertise. Yet the Jews were also subject to increasingly severe restrictions. The Jewish community at Venice, which absorbed large numbers of Iberian Jews and Marranos, formed the first ghetto (the word itself is Venetian, first used in 1516). The practice of confining Jews into walled quarters, locked at night, became the common social practice of early modern states, at least in the central and eastern parts of the continent. The Sephardim, who continued to speak a form of Spanish known as Ladino, established large and prosperous colonies in Ottoman cities—Salonika, Istanbul, and Cairo among them. On balance, however, the early modern period in Europe was socially and culturally a dark age for Jewry.

Is there a single factor that can explain the social his-

tory of Europe's 16th century? Many have been proposed: population growth, overseas discoveries, the emergence of a world economic system, American treasure, profit inflation, capital accumulation, protoindustrialization, the Renaissance or Reformation. Perhaps the most decisive change was progress toward more integrated systems of social organization and action and toward wider and tighter social networks. The western monarchies overcame much of the political localism of the medieval world and set a model that even divided Italy and Germany would eventually emulate. Economic integration advanced even more rapidly; markets in foodstuffs, spices, luxuries, and money extended throughout the continent: The skilled banker could marshal funds from all the continent's money markets; silks from Lucca were sold in Poland. Cities formed into hierarchies, still on a regional basis but surpassing in their effectiveness the loose associations of medieval urban places. To be sure, competition among the centralized states often led to destructive wars and terrible waste of resources; and the quest for unity brought shameful persecution upon those who could not or would not conform to the dominant culture. (D.He.)

POLITICS AND DIPLOMACY

The state of European politics. In the 15th century, changes in the structure of European polity, accompanied by a new intellectual temper, suggested to such observers as the philosopher and clerical statesman Nicholas of Cusa that the "Middle Age" had attained its conclusion and a new era had begun. The Papacy, the symbol of the spiritual unity of Christendom, lost much of its prestige in the Great Western Schism and the conciliar movement and became infected with the lay ideals prevailing in the Italian peninsula. In the 16th century, the Protestant Reformation reacted against the worldliness and corruption of the Holy See, and the Roman Catholic church responded in its turn by a revival of piety known as the Counter-Reformation. While the forces that were to erupt in the Protestant movement were gathering strength, the narrow horizons of the Old World were widened by the expansion of Europe to America and the East. (This section treats the political, diplomatic, and military history of Europe from the Reformation to the Peace of Westphalia. For a discussion of the religious history of this period, see CHRISTIANITY, PROTESTANTISM, and ROMAN CATHOLICISM. The expansion of European culture to new lands is covered in EUROPEAN OVERSEAS EXPLORATION AND EMPIRES, THE HISTORY OF.)

Breakdown of European unity

In western Europe, nation-states emerged under the aegis of strong monarchical governments, breaking down local immunities and destroying the unity of the European *respublica Christiana.* Centralized bureaucracy came to replace medieval government. Underlying economic changes affected social stability. Secular values prevailed in politics, and the concept of a balance of power came to dominate international relations. Diplomacy and warfare were conducted by new methods. Permanent embassies were accredited between sovereigns, and on the battlefield standing armies of professional and mercenary soldiers took the place of the feudal array that had reflected the social structure of the past. At the same time, scientific discoveries cast doubt on the traditional cosmology. The systems of Aristotle and Ptolemy, which had long been sanctified by clerical approval, were undermined by Copernicus, Mercator, Galileo, and Kepler.

Discovery of the New World. In the Iberian Peninsula the impetus of the counteroffensive against the Moors carried the Portuguese to probe the West African coastline and the Spanish to attempt the expulsion of Islām from the western Mediterranean. In the last years of the 15th century, Portuguese navigators established the sea route to India and within a decade had secured control of the trade routes in the Indian Ocean and its approaches. Mercantile interests, crusading and missionary zeal, and scientific curiosity were intermingled as the motives for this epic achievement. Similar hopes inspired Spanish exploitation of the discovery by Christopher Columbus of the Caribbean outposts of the American continent in 1492. The Treaties of Tordesillas and Saragossa in 1494 and 1529 defined the limits of westward Spanish exploration and the eastern ventures of Portugal. The two states acting as the vanguard of the expansion of Europe had thus divided the newly discovered sea lanes of the world between them.

By the time of the Treaty of Saragossa, when Portugal secured the exclusion of Spain from the East Indies, Spain had begun the conquest of Central and South America. In 1519, the year in which Ferdinand Magellan embarked on the westward circumnavigation of the globe, Hernán Cortés launched his expedition against Mexico. The seizure of Peru by Francisco Pizarro and the enforcement of Portuguese claims to Brazil completed the major steps in the Iberian occupation of the continent. By the middle of the century, the age of the conquistadores was replaced by an era of colonization, based both on the procurement of precious metal by Indian labour and on pastoral and plantation economies using imported African slaves. The influx of bullion into Europe became significant in the late 1520s, and from about 1550 it began to produce a profound effect upon the economy of the Old World.

Nation-states and dynastic rivalries. The organization of expansion overseas reflected in economic terms the political nationalism of the European states. This political development took place through processes of internal unification and the abolition of local privileges by the centralizing force of dynastic monarchies. In Spain the union of Aragon, Valencia, and Catalonia under John II of Aragon was extended to association with Castile through the marriage of his son Ferdinand with the Castilian heiress Isabella. The alliance grew toward union after the accession of the two sovereigns to their thrones in 1479 and 1474, respectively, and with joint action against the Moors of Granada, the French in Italy, and the independent kingdom of Navarre. Yet, at the same time, provincial institutions long survived the dynastic union, and the representative assembly (Cortes) of Aragon continued to cling to its privileges when its Castilian counterpart had ceased to play any effective part. Castilian interest in the New World and Aragonese ties in Italy, moreover, resulted in the ambivalent nature of Spanish 16th-century policy, with its uneasy alternation between the Mediterranean and the Atlantic. The monarchy increased the central power by the absorption of military orders and the adaptation of the Hermandad, or police organization, and the Inquisition for political purposes. During the reign of Charles I (the emperor Charles V) centralization was quickened by the importation of Burgundian conciliar methods of government, and in the reign of his son Philip II Spain was in practice an autocracy.

The unification of Spain

Other European monarchies imitated the system devised by Roman-law jurists and administrators in the Burgundian dominions along the eastern borders of France. In England and France the Hundred Years' War (conventionally 1337–1453) had reduced the strength of the aristocracies, the principal opponents of monarchical authority. The pursuit of strong, efficient government by the Tudors in England, following the example of their Yorkist predecessors, found a parallel in France under Louis XI and Francis I. In both countries revision of the administrative and judicial system proceeded through conciliar institutions, although in neither case did it result in the unification of different systems of law. A rising class of professional administrators came to fulfill the role of the king's executive. The creation of a central treasury under Francis I brought an order into French finances already achieved in England through Henry VII's adaptation of the machinery of the royal household. Henry VIII's minister, Thomas Cromwell, introduced an aspect of modernity into English fiscal administration by the creation of courts of revenue on bureaucratic lines. In both countries, the monarchy extended its influence over the government of the church. The unrestricted ability to make law was established by the English crown in partnership with Parliament. In France the representative Estates-General lost its authority, and sovereignty reposed in the king in council. Supreme courts (*parlements*) possessing the right to register royal edicts imposed a slight and ineffective limitation on the absolutism of the Valois kings. The most

Evolution of government in England and France

able exponent of the reform of the judicial machinery of the French monarch was Charles IX's chancellor, Michel de L'Hôpital, but his reforms in the 1560s were frustrated by the anarchy of the religious wars. In France the middle class aspired to ennoblement in the royal administration and mortgaged their future to the monarchy by investment in office and the royal finances. In England, on the other hand, a greater flexibility in social relations was preserved, and the middle class engaged in bolder commercial and industrial ventures.

Territorial unity under the French crown was attained through the recovery of feudal appanages (alienated to cadet branches of the royal dynasty) and, as in Spain, through marriage alliances. Brittany was regained in this way, although the first of the three Valois marriages with Breton heiresses also set in train the dynastic rivalry of Valois and Habsburg. When Charles VIII of France married Anne of Brittany, he stole the bride of the Austrian archduke and future emperor Maximilian I and also broke his own engagement to Margaret of Austria, Maximilian's daughter by Mary of Burgundy. Margaret's brother Philip, however, married Joan, heiress of Castile and Aragon, so that their son eventually inherited not only Habsburg Germany and the Burgundian Netherlands but also Spain, Spanish Italy, and America. The dominions of Charles V thus encircled France and incorporated the wealth of Spain overseas. Even after the division of this vast inheritance between his son, Philip II of Spain, and his brother, the emperor Ferdinand I, the conflict between the Habsburgs and the French crown dominated the diplomacy of Europe for more than a century.

The principal dynastic conflict of the age was less unequal than it seemed, for the greater resources of Charles V were offset by their cumbrous disunity and by local independence. In the Low Countries he was able to complete the Seventeen Provinces by new acquisitions, but, although the coordinating machinery of the Burgundian dukes remained in formal existence, Charles's regents were obliged to respect local privileges and to act through constitutional forms. In Germany, where his grandfather Maximilian I had unsuccessfully tried to reform the constitution of the Holy Roman Empire, Charles V could do little to overcome the independence of the lay and ecclesiastical princes, the imperial knights, and the free cities. The revolts of the knights (1522) and the peasantry (1525), together with the political disaggregation imposed by the Reformation, rendered the empire a source of weakness. Even in Spain, where the rebellion of the *comuneros* took place in 1520–21, his authority was sometimes flouted. His allies, England and the papacy, at times supported France to procure their own profit. France, for its part, possessed the advantages of internal lines of communication and a relatively compact territory, while its alliance with the Ottoman Empire maintained pressure on the Habsburg defenses in southeast Europe and the Mediterranean. Francis I, however, like his predecessors Charles VIII and Louis XII, made the strategic error of wasting his strength in Italy, where the major campaigns were fought in the first half of the century. Only under Henry II was it appreciated that the most suitable area for French expansion lay toward the Rhine.

Turkey and eastern Europe. A contemporary who rivaled the power and prestige of Francis I and Charles V was the ruler of the Ottoman Empire, the sultan Süleyman I the Magnificent (1520–66). With their infantry corps d'élite (the janissaries), their artillery, and their cavalry, or *sipahis,* the Ottomans were the foremost military power in Europe, and it was fortunate for their Christian adversaries that Eastern preoccupations prevented them from taking full advantage of Western disunity. A counterpoise was provided by the rise of the powerful military order of the Ṣafavids in Persia—hostile to the orthodox Ottomans through their acceptance of the heretical Islāmic cult of the Shī'ites. Ottoman strength was further dissipated by the need to enforce the allegiance of Turkmen begs in Anatolia and of the chieftains of the Caucasus and Kurdistan and to maintain the conquest of the sultanate of Syria and Egypt by Süleyman's predecessor, Selim I. Süleyman himself overran Iraq and even challenged Portuguese dominion of the Indian Ocean from his bases in Suez and Basra. The Crimean Tatars acknowledged his suzerainty, as did the corsair powers of Algiers, Tunis, and Tripoli. His armies conquered Hungary in 1526 and threatened Vienna in 1529. With the expansion of his authority along the North African coast and the Adriatic littoral, it seemed for a time as if the Mediterranean, like the Black Sea and the Aegean, might become an Ottoman lake.

Ottoman military power

Though it observed the forms of an Islāmic legal code, Turkish rule was an unlimited despotism, suffering from none of the financial and constitutional weaknesses of Western states. With its disciplined standing army and its tributary populations, the Ottoman Empire feared no internal threat except during the periods of disputed succession, which continued to occur despite a law empowering the reigning sultan to put to death collateral heirs. It was not unusual for the sultan to content himself with the overlordship of frontier provinces. Moldavia and Walachia were for a time held in this fashion, and in Transylvania the vaivode John Zápolya gladly accepted Süleyman as his master in return for support against Ferdinand of Austria.

Despite the expeditions of Charles V against Algiers and Tunis, and the inspired resistance of Venice and Genoa in the war of 1537–40, the Ottomans retained the intiative in the Mediterranean until several years after the death of Süleyman. The Knights of St. John were driven from Rhodes and Tripoli and barely succeeded in retaining Malta. Even after Spain, the papacy, Venice, and Genoa had crushed the Turkish armament in 1571 in the Battle of Lepanto, the Ottomans took Cyprus and recovered Tunis from the garrison installed by the allied commander, Don John of Austria. North Africa remained an outpost of Islām and its corsairs continued to harry Christian shipping, but the Ottoman Empire did not again threaten Europe by land and sea until late in the 17th century.

Alliances in eastern Europe

Poland, Lithuania, Bohemia, and Hungary were all loosely associated at the close of the 15th century under rulers of the Jagiellon dynasty. In 1569, three years before the death of the last Jagiellon king of Lithuania-Poland, these two countries merged their separate institutions by the Union of Lublin. Thereafter the Polish nobility and the Roman Catholic faith dominated the Orthodox lands of Lithuania and held the frontiers against Muscovy, the Cossacks, and the Tatars. Bohemia and the vestiges of independent Hungary were regained by the Habsburgs as a result of dynastic marriages, which the emperor Maximilian I planned as successfully in the east as he did in the west. When Louis II of Hungary died fighting the Ottomans at Mohács in 1526, Archduke Ferdinand of Austria obtained both crowns and endeavoured to affirm the hereditary authority of his dynasty against aristocratic insistence on the principle of election. In 1619, Habsburg claims in Bohemia became the ostensible cause of the Thirty Years' War, when the Diet of Prague momentarily succeeded in deposing Ferdinand II.

In the 16th century, eastern Europe displayed the opposite tendency to the advance of princely absolutism in the West. West of the Carpathians and in the lands drained by the Vistula and the Dnestr, the landowning class achieved a political independence that weakened the power of monarchy. The towns entered a period of decline, and the propertied class, though divided by rivalry between the magnates and the lesser gentry, everywhere reduced their peasantry to servitude. In Poland and Bohemia the peasants were reduced to serfdom in 1493 and 1497, respectively, and in free Hungary the last peasant rights were suppressed after the rising of 1514. The gentry, or *szlachta,* controlled Polish policy in the Sejm (parliament), and, when the first Vasa king, Sigismund III, tried to reassert the authority of the crown after his election in 1587, the opportunity had passed. Yet, despite the anarchic quality of Polish politics, the aristocracy maintained and even extended the boundaries of the state. In 1525 they compelled the submission of the secularized Teutonic Order in East Prussia, resisted the pressure of Muscovy, and pressed to the southeast, where communications with the Black Sea had been closed by the Ottomans and their tributaries.

Farther to the east the grand principality of Moscow

The empire of Ivan the Great

emerged as a new and powerful despotism. Muscovy, and not Poland, became the heir to Kiev during the reign of Ivan III the Great in the second half of the 15th century. By his marriage with the Byzantine princess Sofia (Zoë) Palaeologus, Ivan also laid claim to the traditions of Constantinople. His capture of Novgorod and repudiation of Tatar overlordship began a movement of Muscovite expansion, which was continued by the seizure of Smolensk by his son Vasily (Basil) III and by the campaigns of his grandson Ivan IV the Terrible (1533–84). The latter destroyed the khanates of Kazan and Astrakhan and reached the Baltic by his conquest of Livonia from Poland and the Knights of the Sword. He was the first to use the title of tsar, and his arbitrary exercise of power was more ruthless and less predictable than that of the Ottoman sultan. After his death Muscovy was engulfed in the Time of Troubles, when Polish, Swedish, and Cossack armies devastated the land. The accession of the Romanov dynasty in 1613 heralded a period of gradual recovery. Except for occasional embassies, the importation of a few Western artisans, and the reception of Tudor trading missions, Muscovy remained isolated from the West. Despite its relationship with Greek civilization, it knew nothing of the Renaissance. Though it experienced a schism within its own Orthodox faith, it was equally untouched by Reformation and Counter-Reformation, the consequences of which convulsed western Europe in the late 16th century.

Reformation and Counter-Reformation. In a sense, the Reformation was a protest against the secular values of the Renaissance. No Italian despots better represented the profligacy, the materialism, and the intellectual hedonism that accompanied these values than did the three Renaissance popes, Alexander VI, Julius II, and Leo X. Among those precursors of the reformers who were conscious of the betrayal of Christian ideals were figures so diverse as the Ferraran monk Savonarola, the Spanish statesman Cardinal Jiménez, and the humanist scholar Erasmus.

The corruption of the religious orders and the cynical abuse of the fiscal machinery of the church provoked a movement that at first demanded reform from within and ultimately chose the path of separation. When the Augustinian monk Martin Luther protested against the sale of indulgences in 1517, he found himself obliged to extend his doctrinal arguments until his stand led him to deny the authority of the pope. In the past, as in the controversies between pope and emperor, such challenges had resulted in mere temporary disunity. In the age of nation-states, the political implications of the dispute resulted in the irreparable fragmentation of clerical authority.

Luther's impact on Germany

Luther had chosen to attack a lucrative source of papal revenue, and his intractable spirit obliged Leo X to excommunicate him. The problem became of as much concern to the emperor as it was to the pope, for Luther's eloquent writings evoked a wave of enthusiasm throughout Germany. The reformer was by instinct a social conservative and supported existing secular authority against the upthrust of the lower orders. Although the Diet of Worms accepted the excommunication in 1521, Luther found protection among the princes. In 1529 the rulers of electoral Saxony, Brandenburg, Hessen, Lüneberg, and Anhalt signed the "protest" against an attempt to enforce obedience. By this time, Charles V had resolved to suppress Protestantism and to abandon conciliation. In 1527 his mutinous troops had sacked Rome and secured the person of Pope Clement VII, who had deserted the imperial cause in favour of Francis I after the latter's defeat at the Battle of Pavia. The sack of Rome proved a turning point both for the emperor and the humanist movement that he had patronized. The humanist scholars were dispersed, and the initiative for reform then lay in the hands of the more violent and uncompromising party. Charles V himself experienced a revulsion of conscience that placed him at the head of the Roman Catholic reaction. The empire he ruled in name was now divided into hostile camps. The Catholic princes of Germany had discussed measures for joint action at Regensburg in 1524; in 1530 the Protestants formed a defensive league at Schmalkalden. Reconciliation was attempted in 1541 and 1548, but the German rift could no longer be healed.

Lutheranism laid its emphasis doctrinally on justification by faith and politically on the God-given powers of the secular ruler. Other Protestants reached different conclusions and diverged widely from one another in their interpretation of the sacraments. In Geneva, Calvinism enforced a stern moral code and preached the mystery of grace with predestinarian conviction. It proclaimed the separation of church and state, but in practice its organization tended to produce a type of theocracy. Huldrych Zwingli and Heinrich Bullinger in Zürich taught a theology not unlike Calvin's but preferred to see government in terms of the godly magistrate. On the left wing of these movements were the Anabaptists, whose pacifism and mystic detachment were paradoxically associated with violent upheavals.

Lutheranism established itself in northern Germany and Scandinavia and for a time exercised a wide influence both in eastern Europe and in the west. Where it was not officially adopted by the ruling prince, however, the more militant Calvinist faith tended to take its place. Calvinism spread northward from the upper Rhine and established itself firmly in Scotland and in southern and western France. Friction between Rome and nationalist tendencies within the Catholic church facilitated the spread of Protestantism. In France the Gallican church was traditionally nationalist and antipapal in outlook, while in England the Reformation in its early stages took the form of the preservation of Catholic doctrine and the denial of papal jurisdiction. After periods of Calvinist and then of Roman Catholic reaction, the Church of England achieved a measure of stability with the Elizabethan religious settlement.

Spread of Calvinism

In the years between the papal confirmation of the Jesuit order in 1540 and the formal dissolution of the Council of Trent in 1563, the Roman Catholic church responded to the Protestant challenge by purging itself of the abuses and ambiguities that had opened the way to revolt. Thus prepared, the Counter-Reformation embarked upon recovery of the schismatic branches of Western Christianity. Foremost in this crusade were the Jesuits, established as a well-educated and disciplined arm of the papacy by Ignatius Loyola. Their work was made easier by the Council of Trent, which did not, like earlier councils, result in the diminution of papal authority. The council condemned such abuses as pluralism, affirmed the traditional practice in questions of clerical marriage and the use of the Bible, and clarified doctrine on issues such as the nature of the Eucharist, divine grace, and justification by faith. The church thus made it clear that it was not prepared to compromise; and, with the aid of the Inquisition and the material resources of the Habsburgs, it set out to reestablish its universal authority. It was of vital importance to this task that the popes of the Counter-Reformation were men of sincere conviction and initiative who skillfully employed diplomacy, persuasion, and force against heresy. In Italy, Spain, Bavaria, Austria, Bohemia, Poland, and the southern Netherlands (the future Belgium), Protestant influence was destroyed. (J.H.McM.S.)

Diplomacy in the age of the Reformation. This was a golden era for diplomats and international lawyers. To the network of alliances that became established throughout Europe during the Renaissance, the Reformation added confessional pacts. Unfortunately, however, the two systems were not always compatible. The traditional amity between Castile and England, for example, was fatally undermined when the Tudor dynasty embraced Protestantism after 1532; and the "auld alliance" between Scotland and France was likewise wrecked by the progress of the Reformation in Scotland after 1560. Moreover, in many countries, the confessional divisions of Christendom after Luther created powerful religious minorities who were prepared to look abroad for guarantees of protection and solidarity: for example, the English Catholics to Spain and the French, German, and Dutch Calvinists to England.

These developments created a situation of chronic political instability. On the one hand, the leaders of countries which themselves avoided religious fragmentation (such as Spain) were often unsure whether to frame their foreign policy according to confessional or political advantage. On the other hand, the foreign policy of religiously divided

states, such as France, England, and the Dutch Republic, oscillated often and markedly because there was no consensus among the political elite concerning the correct principles upon which foreign policy should be based.

The complexity of the diplomatic scene called for unusual skills among the rulers of post-Reformation Europe. Seldom has the importance of personality in shaping events been so great. The quixotic temperaments and mercurial designs of even minor potentates exerted a disproportionate influence on the course of events. Nevertheless, behind the complicated interplay of individuals and events, two constants may be detected. First, statesmen and churchmen alike consistently identified politics and religion as two sides of the same coin. Supporters of the Bohemian rebellion of 1618, for example, frequently stated that "religion and liberty stand or fall together": that is, a failure to defend and maintain religious liberty would necessarily lead to the loss of political freedom. The position of Emperor Ferdinand II (1619–37) was exactly the same. "God's blessing cannot be received," he informed his subjects, "by a land in which prince and vassals do not both fervently uphold the one true Catholic faith."

The two diplomatic constants

These two views, precisely because they were identical, were totally incompatible. That their inevitable collision should have so often produced prolonged wars, however, was due to the second "constant": the desire of political leaders everywhere, even on the periphery of Europe, to secure a balance of power on the continent favourable to their interests. It is scarcely surprising that, when any struggle became deadlocked, the local rulers should look about for foreign support; it is more noteworthy that their neighbours were normally ready and eager to provide it. Queen Elizabeth I of England (1558–1603) offered substantial support after 1585 to the Dutch rebels against Philip II and after 1589 to the Protestant Henry IV of France against his more powerful Catholic subjects; Philip II of Spain (1556–98), for his part, sent troops and treasure to the French Catholics, while his son Philip III (1598–1621) did the same for the German Catholics.

This willingness to assist arose because every court in Europe believed in a sort of domino theory, which argued that, if one side won a local war, the rest of Europe would inevitably be affected. The Spanish version of the theory was expressed in a letter from Archduchess Isabella, regent of the Spanish Netherlands, to her master Philip IV in 1623: "It would not be in the interests of Your Majesty to allow the Emperor or the Catholic cause to go down, because of the harm it would do to the possessions of Your Majesty in the Netherlands and Italy." Thus the religious tensions released by the Reformation eventually pitted two incompatible ideologies against each other; this in turn initiated civil wars that lasted 30 years (in the case of France and Germany) and even 80 years (in the Netherlands), largely because all the courts of Europe saw that the outcome of each confrontation would affect the balance of power for a decade, a generation, perhaps forever. (N.G.P.)

The Wars of Religion. Germany, France, and the Netherlands each achieved a settlement of the religious problem by means of war, and in each case the solution contained original aspects. In Germany the territorial formula of *cuius regio, eius religio* applied—that is, in each petty state the population had to conform to the religion of the ruler. In France, the Edict of Nantes in 1598 embraced the provisions of previous treaties and accorded the Protestant Huguenots toleration within the state, together with the political and military means of defending the privileges that they had exacted. The southern Netherlands remained Catholic and Spanish, but the Dutch provinces formed an independent Protestant federation in which republican and dynastic influences were nicely balanced. Nowhere was toleration accepted as a positive moral principle, and seldom was it granted except through political necessity.

Cuius regio

There were occasions when the Wars of Religion assumed the guise of a supranational conflict between Reformation and Counter-Reformation. Spanish, Savoyard, and papal troops supported the Catholic cause in France against Huguenots aided by Protestant princes in England and Germany. In the Low Countries, English, French, and German armies intervened; and at sea Dutch, Huguenot, and English corsairs fought the Battle of the Atlantic against the Spanish champion of the Counter-Reformation. In 1588 the destruction of the Spanish Armada against England was intimately connected with the progress of the struggles in France and the Netherlands.

Behind this ideological grouping of the powers, national, dynastic, and mercenary interests generally prevailed. The Lutheran duke Maurice of Saxony assisted Charles V in the first Schmalkaldic War in 1547 in order to win the Saxon electoral dignity from his Protestant cousin, John Frederick; while the Catholic king Henry II of France supported the Lutheran cause in the second Schmalkaldic War in 1552 to secure French bases in Lorraine. John Casimir of the Palatinate, the Calvinist champion of Protestantism in France and the Low Countries, maintained an understanding with the neighbouring princes of Lorraine, who led the ultra-Catholic Holy League in France. In the French conflicts, Lutheran German princes served against the Huguenots, and mercenary armies on either side often fought against the defenders of their own religion. On the one hand, deep divisions separated Calvinist from Lutheran; and, on the other hand, political considerations persuaded the moderate Catholic faction, the Politiques, to oppose the Holy League. The national and religious aspects of the foreign policy of Philip II of Spain were not always in accord. Mutual distrust existed between him and his French allies, the family of Guise, because of their ambitions for their niece Mary Stuart. His desire to perpetuate French weakness through civil war led him at one point to negotiate with the Huguenot leader, Henry of Navarre (afterward Henry IV of France). His policy of religious uniformity in the Netherlands alienated the most wealthy and prosperous part of his dominions. Finally, his ambition to make England and France the satellites of Spain weakened his ability to suppress Protestantism in both countries.

In 1562, seven years after the Peace of Augsburg had established a truce in Germany on the basis of territorialism, France became the centre of religious wars which endured, with brief intermissions, for 36 years. The political interests of the aristocracy and the vacillating policy of balance pursued by Henry II's widow, Catherine de Médicis, prolonged these conflicts. After a period of warfare and massacre, in which the atrocities of St. Bartholomew's Day (1572) were symptomatic of the fanaticism of the age, Huguenot resistance to the crown was replaced by Catholic opposition to the monarchy's policy of conciliation to Protestants at home and anti-Spanish alliances abroad. The revolt of the Holy League against the prospect of a Protestant king in the person of Henry of Navarre released new forces among the Catholic lower classes, which the aristocratic leadership was unable to control. Eventually Henry won his way to the throne after the extinction of the Valois line, overcame separatist tendencies in the provinces, and secured peace by accepting Catholicism. The policy of the Bourbon dynasty resumed the tradition of Francis I, and under the later guidance of Cardinal Richelieu the potential authority of the monarchy was realized.

Religious conflict in France

In the Netherlands the wise Burgundian policies of Charles V were largely abandoned by Philip II and his lieutenants. Taxation, the Inquisition, and the suppression of privileges for a time provoked the combined resistance of Catholic and Protestant. The house of Orange, represented by William I the Silent and Louis of Nassau, acted as the focus of the revolt; and, in the undogmatic and flexible personality of William, the rebels found leadership in many ways similar to that of Henry of Navarre. The sack of the city of Antwerp by mutinous Spanish soldiery in 1576 (three years after the dismissal of Philip II's autocratic and capable governor, the Duke de Alba) completed the commercial decline of Spain's greatest economic asset. In 1579 Alessandro Farnese, Duke di Parma, succeeded in recovering the allegiance of the Catholic provinces, while the Protestant north declared its independence. French and English intervention failed to secure the defeat of Spain, but the dispersal of the Armada and the diversion

of Parma's resources to aid the Holy League in France enabled the United Provinces of the Netherlands to survive. A 12-year truce was negotiated in 1609, and when the campaign began again it merged into the general conflict of the Thirty Years' War, which, like the other wars of religion of this period, was fought mainly for confessional security and political gain. (J.H.McM.S.)

The Thirty Years' War. *The crisis in Germany.* The war originated with dual crises at the continent's centre: one in the Rhineland and the other in Bohemia, both part of the Holy Roman Empire.

"The dear old Holy Roman Empire,
How does it stay together?"

asked the tavern drinkers in Goethe's *Faust*—and the answer is no easier to find today than in the late 18th, or early 17th, century. The Holy Roman Empire of the German Nation was a land of many polities. In the empire there were some 1,000 separate, semiautonomous political units, many of them very small—such as the Imperial Knights, direct vassals of the emperor and particularly numerous in the southwest, who might each own only part of one village—and others comparable in size with smaller independent states elsewhere, such as Scotland or the Dutch Republic. At the top came the lands of the Austrian Habsburgs, covering the elective kingdoms of Bohemia and Hungary, as well as Austria, the Tyrol, and Alsace, with about 8,000,000 inhabitants; next came electoral Saxony, Brandenburg, and Bavaria, with more than 1,000,000 subjects each; and then the Palatinate, Hesse, Trier, and Württemberg, with about 500,000 each.

Organization of the Holy Roman Empire

These were large polities, indeed, but they were weakened by three factors. First, they did not accept primogeniture: Hesse had been divided into four portions at the death of Landgrave Philip the Magnanimous, Luther's patron, in 1567; the lands of the Austrian Habsburgs were partitioned in 1564 and again in 1576. Second, many of the states were geographically fragmented: thus the Palatinate was divided into an Upper County, adjoining the borders of both Bohemia and Bavaria, and a Lower County, on the middle Rhine. These factors had, in the course of time, created in Germany a balance of power between the states. The territorial strength of the Habsburgs may have brought them a monopoly of the imperial title from 1438 onward, but they could do no more: the other princes, when threatened, were able to form alliances whose military strength was equal to that of the emperor himself. However, the third weakness—the religious upheaval of the 16th century—changed all that: princes who had formerly stood together were now divided by religion. Swabia, for example, more or less equal in area to modern Switzerland, included 68 secular and 40 spiritual princes and also 32 imperial free cities. By 1618 more than half of these rulers and almost exactly half of the population were Catholic; the rest were Protestant. Neither bloc was prepared to let the other mobilize an army. Similar paralysis was to be found in most other regions: the Reformation and Counter-Reformation had separated Germany into hostile but evenly balanced confessional camps.

The Religious Peace of Augsburg in 1555 had put an end to 30 years of sporadic confessional warfare in Germany between Catholics and Lutherans by creating a layered



The Thirty Years' War.

structure of legal securities for the people of the empire. At the top was the right (known as *cuius regio, eius religio*) of every secular ruler, from the seven electors down to the imperial knights, to dictate whether their subjects' religion was to be Lutheran or Catholic (the only officially permitted creeds). The only exceptions to this rule were the imperial free cities, where both Lutherans and Catholics were to enjoy freedom of worship, and the Catholic ecclesiastical states, where bishops and abbots who wished to become Lutherans were obliged to resign first. The latter provision, known as the *reservatum ecclesiasticum,* gave rise to a war in 1583–88 when the archbishop of Cologne declared himself a Protestant but refused to resign: in the end a coalition of Catholic princes, led by the duke of Bavaria, forced him out.

This "War of Cologne" was a turning point in the religious history of Germany. Until then, the Catholics had been on the defensive, losing ground steadily to the Protestants. Even the decrees of the Council of Trent, which animated Catholics elsewhere, failed to strengthen the position of the Roman church in Germany. After the successful struggle to retain Cologne, however, Catholic princes began to enforce the *cuius regio* principle with rigour. In Bavaria, as well as in Würzburg, Bamberg, and other ecclesiastical states, Protestants were given the choice of either conversion or exile. Most of those affected were adherents of the Lutheran church, already weakened by defections to Calvinism, a new creed that had scarcely a German adherent at the time of the Religious Peace of Augsburg. The rulers of the Palatinate (1560), Nassau (1578), Hesse-Kassel (1603), and Brandenburg (1613) all abandoned Lutheranism for the new confession, as did many lesser rulers and several towns. Small wonder that the Lutherans came to detest the Calvinists even more than they loathed the Catholics.

These religious divisions created a complex confessional pattern in Germany. By the first decade of the 17th century, the Catholics were firmly entrenched south of the Danube and the Lutherans northeast of the Elbe; but the areas in between were a patchwork quilt of Calvinist, Lutheran, and Catholic, and in some places one could find all three. One such was Donauwörth, an independent city just across the Danube from Bavaria, obliged (by the Peace of Augsburg) to tolerate both Catholics and Protestants. But for years the Catholic minority had not been permitted full rights of public worship. When in 1606 the priests tried to hold a procession through the streets, they were beaten and their relics and banners were desecrated. Shortly afterward, an Italian Capuchin, Fray Lorenzo da Brindisi, later canonized, arrived in the city and was himself mobbed by a Lutheran crowd chanting "Capuchin, Capuchin, scum, scum." He heard from the local clergy of their plight and promised to find redress. Within a year, Fray Lorenzo had secured promises of aid from Duke Maximilian of Bavaria and Emperor Rudolf II. When the Lutheran magistrates of Donauwörth flatly refused to permit their Catholic subjects freedom of worship, the Bavarians marched into the city and restored Catholic worship by force (December 1607). Maximilian's men also banned Protestant worship and set up an occupation government that eventually transferred the city to direct Bavarian rule.

Religious strife at Donauwörth

These dramatic events thoroughly alarmed Protestants elsewhere in Germany. Was this, they wondered, the first step in a new Catholic offensive against heresy? Elector Frederick IV of the Palatinate took the lead. On May 14, 1608, he formed the Evangelical, or Protestant, Union, an association to last for 10 years, for self-defense. At first, membership remained restricted to Germany, although the elector's leading adviser, Christian of Anhalt, wished to extend it, but before long a new crisis rocked the empire and turned the German union into a Protestant International.

The new crisis began with the death of John William, the childless duke of Cleves-Jülich, in March 1609. His duchies, occupying a strategic position in the Lower Rhineland, had both Protestant and Catholic subjects, but both of the main claimants to the inheritance were Protestants; under the *cuius regio* principle, their succession would lead to the expulsion of the Catholics. The emperor therefore refused to recognize the Protestant princes' claim. Since both were members of the Union, they solicited, and received, promises of military aid from their colleagues; they also received, via Christian of Anhalt, similar promises from the kings of France and England. This sudden accretion in Protestant strength caused the German Catholics to take countermeasures: a Catholic League was formed between Duke Maximilian of Bavaria and his neighbours on July 10, 1609, soon to be joined by the ecclesiastical rulers of the Rhineland and receiving support from Spain and the Papacy. Again, reinforcement for one side provoked countermeasures. The Union leaders signed a defensive treaty with England in 1612 (cemented by the marriage of the Union's director, the young Frederick V of the Palatine, to the king of England's daughter) and with the Dutch Republic in 1613.

The Protestant Union and the Catholic League

At first sight, this resembles the pyramid of alliances, patiently constructed by the statesmen of Europe 300 years later, which plunged the continent into World War I. But whereas the motive of diplomats before 1914 was fear of political domination, before 1618 it was fear of religious extirpation. The Union members were convinced of the existence of a Catholic conspiracy aimed at rooting out all traces of Protestantism from the empire. This view was shared by the Union's foreign supporters. At the time of the Cleves-Jülich succession crisis, Sir Ralph Winwood, an English diplomat at the heart of affairs, wrote to his masters that, although "the issue of this whole business, if slightly considered, may seem trivial and ordinary," in reality its outcome would "uphold or cast down the greatness of the house of Austria and the church of Rome in these quarters." Such fears were probably unjustified at this time. In 1609 the unity of purpose between pope and emperor was in fact far from perfect, and the last thing Maximilian of Bavaria wished to see was Habsburg participation in the League: rather than suffer it, in 1614 he formed a separate association of his own and in 1616 he resigned from the League altogether. This reduction in the Catholic threat was enough to produce reciprocal moves among the Protestants. Although there was renewed fighting in 1614 over Cleves-Jülich, the members of the Protestant Union had abandoned their militant stance by 1618, when the treaty of alliance came up for renewal. They declared that they would no longer become involved in the territorial wrangles of individual members, and they resolved to prolong their association for only three years more.

Although, to some extent, war came to Germany after 1618 because of the existence of these militant confessional alliances, the continuity must not be exaggerated. Both Union and League were the products of fear; but the grounds for fear seemed to be receding. The English ambassador in Turin, Isaac Wake, was sanguine: "The gates of Janus have been shut," he exulted in late 1617, promising "calm and Halcyonian days not only unto the inhabitants of this province of Italye, but to the greatest part of Christendome." That Wake was so soon proved wrong was due largely to events in the lands of the Austrian Habsburgs over the winter of 1617–18.

The crisis in the Habsburg lands. While the Cleves-Jülich crisis held the attention of western Europe in 1609, the eyes of observers farther east were on Prague, the capital of Bohemia. That elective kingdom (which also included Silesia, Lusatia, and Moravia), together with Hungary, had come to the Habsburg family in 1526. At first they were ruled jointly with Austria by Ferdinand I (brother of Emperor Charles V), but after his death in 1564 the inheritance was divided into three portions: Alsace and Tyrol (known as "Further Austria") went to one of his younger sons; Styria, Carinthia, and Carniola (known as "Inner Austria") went to a second; only the remainder was left for his successor as emperor, Maximilian II.

By 1609 fragmentation had advanced even further: Maximilian's eldest son, Rudolf II (emperor, 1576–1611), ruled only Bohemia; all the rest of his father's territories had been acquired, the previous year, by a younger son, Matthias. The new ruler had come to power not through strength or talent, however, but by the exploitation of the

religious divisions of his subjects. During the 1570s the Protestants of Austria, Bohemia, and Hungary had used their strength of numbers and control of local representative assemblies to force the Habsburgs to grant freedom of worship to their Protestant subjects. This was clearly against the *cuius regio* principle, and everyone knew it. In 1599 the ruler of Inner Austria, Archduke Ferdinand, began a campaign of forcible re-Catholicization among his subjects, which proved entirely successful. But, when Rudolf II launched the same policy in Hungary shortly afterward, there was a revolt, and the rebels offered the Hungarian crown to Matthias in return for guarantees of toleration. The Bohemians decided to exploit Rudolf's temporary embarrassment by pressing him to grant similarly far-reaching concessions to the non-Catholic majority of that kingdom. The "Letter of Majesty" (Majestätsbrief) signed by Rudolf on July 9, 1609, granted full toleration to Protestants and created a standing committee of the Estates, known as "the Defensors," to ensure that the settlement would be respected.

The Letter of Majesty

Rudolf II—a recluse who hid in a world of fantasy and alchemy in his Hradčany palace above Prague, a manic depressive who tried to take his own life on at least one occasion—proved to be incapable of keeping to the same policy for long. In 1611 he tried to revoke the Letter of Majesty and to depose the Defensors by sending a small Habsburg army into Prague, but a force of superior strength was mobilized against the invaders and the Estates resolved to depose Rudolf and offer their crown to Matthias. The emperor, broken in mind and body, died in January 1612. All his territories were then ruled by his brother, who also succeeded him as Holy Roman emperor later in the year. The alliance with the Protestant Estates that brought about Matthias's elevation, however, did not long continue once he was in power. The new ruler sought to undo the concessions he had made, and he looked for support to his closest Habsburg relatives: his brother Albert, ruler of the Spanish Netherlands; his cousin Ferdinand, ruler of Inner Austria; and his nephew Philip III, king of Spain. All three, however, turned him down.

Albert had in 1609 succeeded in bringing the war between Spain and the Dutch Republic to a temporary close with the Twelve Years' Truce. The last thing he wanted was to involve his ravaged country in supplying men and money to Vienna, perhaps provoking countermeasures from Protestants nearer home. Archduke Ferdinand, although willing to aid Matthias to uphold his authority (not least because he regarded himself as heir presumptive to the childless Matthias), was prevented from doing so by the outbreak of war between his Croatian subjects and the neighbouring republic of Venice (the Uskok War, 1615–18). Philip of Spain was also involved in war: in 1613–15 and 1616–17, Spanish forces in Lombardy fought the troops of the duke of Savoy over the succession to the childless duke of Mantua. Spain could therefore aid neither Matthias nor Ferdinand.

In 1617, however, papal diplomats secured a temporary settlement of the Mantuan question, and Spanish troops hastened to the aid of Ferdinand. Before long, Venice made overtures for peace, and the archduke was able to leave his capital at Graz in order to join Matthias. The emperor, old and infirm, was anxious to establish Ferdinand as his heir, and, in the autumn of 1617, the Estates of both Bohemia and Hungary were persuaded to recognize the archduke unconditionally as king-designate. On the strength of this, Ferdinand proceeded over the winter of 1617–18 to halt the concessions being made to Protestants. He created a council of regency for Bohemia that was overwhelmingly Catholic, and it soon began to censor works printed in Prague and to prevent non-Catholics from holding government office. More inflammatory still, the regents ordered Protestant worship to stop in towns on church lands (which they claimed were not included in the Letter of Majesty).

The Defensors created by the Letter of Majesty expressed strong objection to these measures and summoned the Estates of the realm to meet in May 1618. When the regents declared the meeting illegal, the Estates invaded the council chamber and threw two Catholic regents, together with their secretary, from the window. Next, a provisional government (known as the Directors) was created and a small army was raised.

The Defenestration of Prague

Apart from the famous "defenestration," the events in Prague in May 1618 were, superficially, little different from those in 1609 and 1611. Yet no 30-year struggle arose from those earlier crises. The crucial difference lay in the involvement of foreign powers: in 1609 and 1611 the Habsburgs, represented by Rudolf and Matthias, had given in to their subjects' demands; in 1618, led by Ferdinand, they did not. At first his defiant stance achieved nothing, for the army of the rebels expelled loyal troops from almost every part of the kingdom while their diplomats secured declarations of support from Silesia, Lusatia, and Upper Austria almost at once and from Moravia and Lower Austria shortly afterward. In May 1619 the rebel army even laid siege to Ferdinand in Vienna. Within weeks, however, they were forced to withdraw because a major Spanish army, partly financed by the pope, invaded Bohemia.

The appearance of Spanish troops and papal gold in eastern Europe immediately reawakened the fears of the Protestant rulers of the empire. To the government of Philip III, led by the former ambassador in Vienna, Don Balthasar de Zúñiga, the choice had seemed clear: "Your Majesty should consider," wrote one minister, "which will be of the greater service to you: the loss of these provinces [to the house of Habsburg], or the dispatch of an army of 15 to 20 thousand men to settle the matter." Seen in these terms, Spain could scarcely avoid military intervention in favour of Ferdinand; but to Protestant observers the logic of Spanish intervention seemed aggressive rather than defensive. Dudley Carleton, the English ambassador to the Dutch Republic, observed that the new emperor "flatters himself with prophesies of extirpating the Reformed religion and restoring the Roman church to the ancient greatness" and accurately predicted that, if the Protestant cause were to be "neglected and by consequence suppressed, the Protestant princes adjoining [Bohemia] are like to bear the burden of a victorious army."

This same argument carried weight with the director of the Protestant Union, Frederick V of the Palatinate, parts of whose territories adjoined Bohemia. So, when in the summer of 1619 the Bohemians deposed Ferdinand and offered the crown to Frederick, he was favourably disposed. Some of the elector's advisers favoured rejecting this offer, since "acceptance would surely begin a general religious war"; but others pointed out that such a war was inevitable anyway when the Twelve Years' Truce between Spain and the Dutch Republic expired in April 1621 and argued that allowing the Bohemian cause to fail would merely ensure that the conflict in the Netherlands would be resolved in Spain's favour later, making a concerted Habsburg attack on the Protestants of the empire both ineluctable and irresistible.

Frederick V in Bohemia

Frederick accepted the Bohemian crown and in so doing rekindled the worst fears of the German Catholics. The Catholic League was re-created, and in December 1619 its leaders authorized the levy of an army of 25,000 men to be used as Maximilian of Bavaria thought fit. At the same time, Philip III and Archduke Albert each promised to send a new army into Germany to assist Ferdinand (who had succeeded the late Matthias as Holy Roman emperor). The crisis was now apparent, and, as the Palatine diplomat Count John Albert Solms warned his master,

> If it is true that the Bohemians are about to depose Ferdinand and elect another king, let everyone prepare at once for a war lasting twenty, thirty or forty years. The Spaniards and the House of Austria will deploy all their worldly goods to recover Bohemia.

The underlying cause for the outbreak of a war that would last 30 years was thus the pathological fear of a Catholic conspiracy among the Protestants and the equally entrenched suspicion of a Protestant conspiracy among the Catholics. As a Bohemian noblewoman, Polyxena Lobkovic, perceptively observed from the vantage point of Prague: "Things are now swiftly coming to the pass where either the papists will settle their score with the Protestants, or the Protestants with the papists."

The triumph of the Catholics, 1619–29. Frederick V entered Prague and was crowned king by the rebel Estates in October 1619, but already the Catholic net was closing around him. The axis linking Vienna with Munich, Brussels, and Madrid enjoyed widespread support: subsidies came from Rome and Genoa, while Tuscany and Poland sent troops. Equally serious, states favourable to Frederick's cause were persuaded to remain neutral: Spanish diplomacy kept England out of the war, while French efforts persuaded the Protestant Union to remain aloof from the Bohemian adventure of their leader. The Dutch Republic also did nothing, so that in the summer of 1620 a Spanish army was able to cross from the Netherlands and occupy the Rhine Palatinate. Meanwhile, the armies of the emperor and League, reinforced with Spanish and Italian contingents, invaded the rebel heartland. On November 8, in the first significant battle of the war, at the White Mountain outside Prague, Frederick's forces were routed. The unfortunate prince fled northward, abandoning his subjects to the mercy of the victorious Ferdinand.

Battle of White Mountain

This was total victory, and it might have remained the last word but for events in the Low Countries. Once the Twelve Years' Truce expired in April 1621, the Dutch, fearing a concerted attack by both Spanish and Austrian Habsburgs, decided to provide an asylum for the defeated Frederick and to supply diplomatic and, eventually, military assistance to his cause. In 1622 and again in 1623, armies were raised for Frederick with Dutch money, but they were defeated. Worse, the shattered armies retreated toward the Netherlands, drawing the Catholic forces behind them. It began to seem that a joint Habsburg invasion of the republic was inevitable after all.

The emperor's political position, however, weakened considerably in the course of 1623. Although his armies won impressive victories in the field, they were only able to do so thanks to massive financial and military support from the Catholic League, controlled by Maximilian of Bavaria. Ferdinand II, thanks to the Spanish and papal subsidies, maintained some 15,000 men himself, but the League provided him with perhaps 50,000. Thus Maximilian's armies had, in effect, won Ferdinand's victories and, now that all common enemies had been defeated, Maximilian requested his reward: the lands and electoral title of the outlawed Frederick of the Palatinate. Don Balthasar de Zúñiga, chief minister of Ferdinand's other major ally, Spain, warned that the consequences of acceding to this demand could be serious, but in October 1622 he died, and no one else in Madrid—least of all his successor as principal minister, the Count-Duke of Olivares—had practical experience of German affairs; so in January 1623 the emperor felt able to proceed with the investiture of Maximilian as elector Palatine.

Zúñiga, however, had been right: the electoral transfer provoked an enormous outcry, for it was clearly unconstitutional. The Golden Bull of 1356, which was universally regarded in Germany as the fundamental and immutable law of the empire, ordained that the electorate should remain in the Palatine house in perpetuity. The transfer of 1623 thus undermined a cornerstone of the Constitution, which many regarded as their only true safeguard against absolute rule. Inside Germany, a pamphlet war against Maximilian and Ferdinand began; outside, sympathy for Frederick at last created that international body of support for his cause which had previously been so conspicuously lacking. The Dutch and the Palatine exiles found little difficulty in engineering an alliance involving France, England, Savoy, Sweden, and Denmark that was dedicated to the restoration of Frederick to his forfeited lands and titles (the Hague Alliance, Dec. 9, 1624). Its leader was Christian IV of Denmark (1588–1648), one of the richest rulers in Christendom, who saw a chance to extend his influence in northern Germany under cover of defending "the Protestant cause." He invaded the empire in June 1625.

The Hague Alliance

The Protestants' diplomatic campaign had not gone unnoticed, however. Maximilian's field commander, Count Tilly, warned that his forces alone would be no match for a coalition army and asked that the emperor send reinforcements. Ferdinand obliged: in the spring of 1625 he authorized Albrecht von Wallenstein, military governor of Prague, to raise an imperial army of 25,000 men and to move it northward to meet the Danish threat. Wallenstein's approach forced Christian to withdraw; when the Danes invaded again the following year, they were routed at the Battle of Lutter (Aug. 26, 1626). The joint armies of Tilly and Wallenstein pursued the defeated forces: first they occupied the lands of North German rulers who had declared support for the invasion, then they conquered the Danish mainland itself. Christian made peace in 1629, promising never again to intervene in the empire. His allies had long since withdrawn from the struggle.

The White Mountain delivered the Bohemian rebels into the emperor's grasp; Lutter delivered the rebels' German supporters. After the victories, important new policies were initiated by Ferdinand which aimed at exalting the Catholic religion and his own authority. In the Habsburg provinces there was widespread confiscation of land—perhaps two-thirds of the kingdom of Bohemia changed hands during the 1620s—and a new class of loyal landowners—like Wallenstein—was established. At the same time, the power of the Estates was curtailed and freedom of worship for Protestants was restricted (in some territories) or abolished (in most of the rest). Even a rebellion in Upper Austria in 1626, provoked principally by the persecution of Protestants, failed to change Ferdinand's mind. Indeed, fortified by his success in the Habsburg lands, he decided to implement new policies in the empire. First, disloyal rulers were replaced (the Palatinate went to Maximilian, Mecklenburg to Wallenstein, and so on). Next, serious steps were taken to reclaim church lands that had fallen into Protestant hands. At first this was done on a piecemeal basis, but on March 28, 1629, an Edict of Restitution was issued which declared unilaterally that all church lands secularized since 1552 must be returned at once, that Calvinism was an illegal creed in the empire, and that ecclesiastical princes had the same right as secular ones to insist that their subjects should be of the same religion as their ruler. The last clause, at least, was clearly contrary to the terms of the Peace of Augsburg, which Protestants regarded as a central pillar of the Constitution. There was, however, no opportunity for argument, for the imperial edict was enforced immediately, brutally, by the armies of Wallenstein and Tilly, which now numbered some 200,000 men. The people of the empire seemed threatened with an arbitrary rule against which they had no defense. It was this fear, skillfully exploited once again by Protestant propagandists, which ensured that the war in Germany did not end in 1629 with the defeat of Denmark. Ferdinand may have won numerous military victories, but in doing so he had suffered a serious political defeat. The pens of his enemies proved mightier than the sword.

The crisis of the war, 1629–35. If Maximilian of Bavaria desired the title of elector as his reward for supporting Ferdinand, Spain (for its part) required imperial support for its war against the Dutch. When repeated requests for a direct invasion by Wallenstein's army remained unanswered (largely due to Bavarian opposition), Spain began to think of creating a Baltic navy, with imperial assistance, which would cleanse the inland sea of Dutch shipping and thus administer a body blow to the republic's economy. But the plan aborted, for the imperial army failed in 1628 to conquer the port of Stralsund, selected as the base for the new fleet. Now, with Denmark defeated, Madrid again pleaded for the loan of an imperial army, and this time the request was granted. In the end, however, the troops did not march to the Netherlands: instead, they went to Italy.

The death of the last native ruler of the strategic states of Mantua and Montferrat in December 1627 created dangers in Italy that the Spaniards were unable to ignore and temptations that they were unable to resist. Hoping to forestall intervention by others, Spanish forces from Lombardy launched an invasion, but the garrisons of Mantua and Montferrat declared for the late duke's relative, the French-born duke of Nevers. Nevers lacked the resources to withstand the forces of Spain alone, and he appealed to France for support. Louis XIII (1610–43) and Cardinal Richelieu (chief minister 1624–42) were, however, engaged in a desperate war against their Calvinist subjects;

Spain's invasion of Mantua

only when the rebels had been defeated, early in 1629, was it possible for the king and his chief minister to cross the Mount Cenis Pass and enter Italy. It was to meet this threat that the emperor was asked by Philip IV of Spain (1621–65) to send his troops to Italy rather than to the Netherlands. When Louis XIII launched a second invasion in 1630, some 50,000 imperial troops were brought south to oppose them, reducing the war for Mantua to a stalemate but delivering the Dutch Republic from immediate danger and weakening the emperor's hold on Germany.

Gustav II Adolf of Sweden (1611–32) had spent most of the 1620s at war with Poland, seeking to acquire territory on the southern shore of the Baltic. By the Truce of Altmark (Sept. 26, 1629), with the aid of French and British mediators, Poland made numerous concessions in return for a six-year truce. Gustav lost no time in redeploying his forces: on July 6, 1630, he led a Swedish expeditionary force ashore near Stralsund with the declared intention of saving the "liberties of the empire" and preserving the security of the Baltic.

Despite the defeat of the German Protestants and their allies, Sweden's position was far more favourable than that of Denmark five years earlier. Instead of the two armies that had faced Christian IV, Gustav was opposed by only one, for in the summer of 1630 the emperor's Catholic allies in Germany—led by Maximilian of Bavaria—demanded the dismissal of Wallenstein and the drastic reduction of his expensive army. It was an ultimatum that Ferdinand, with the bulk of his forces tied down in the war of Mantua, could not ignore, even though he thereby lost the services of the one man who might conceivably have retained all the imperial gains of the previous decade and united Germany under a strong monarchy.

The emperor and his German allies, nevertheless, did remain united over the Edict of Restitution: there were to be no concessions in matters of religion and no restoration of forfeited lands. As a result, the German Protestants were driven reluctantly into the arms of Sweden, whose army was increased with the aid of subsidies secured from France and the Dutch. In September 1631 Gustav at last felt strong enough to challenge the emperor's forces in battle: at Breitenfeld, just outside Leipzig in Saxony, he was totally victorious. The main Catholic field army was destroyed, and the Swedish Protestant host overran most of central Germany and Bohemia in the winter of 1631–32. The next summer they occupied Bavaria. Although Gustav died in battle at Lützen on Nov. 16, 1632, his forces were again victorious and his cause was directed with equal skill by his chief adviser, Axel Oxenstierna. In the east, Sweden managed to engineer a Russian invasion of Poland in the autumn of 1632 that tied down the forces of both powers for almost two years. Meanwhile, in Germany, Oxenstierna crafted a military alliance that transferred much of the cost of the war onto the shoulders of the German Protestant states (the Heilbronn League, April 23, 1633). Swedish ascendancy, however, was destroyed in 1634 when Russia made peace with Poland (at Polyanov, June 4) and Spain sent a large army across the Alps from Lombardy to join the imperial forces at the Battle of Nördlingen (September 6). This time the Swedes were decisively beaten and were obliged to withdraw their forces in haste from most of southern Germany.

Swedish control of Germany

Yet Sweden, under Oxenstierna's skillful direction, fought on. Certainly its motives included a desire to defend the Protestant cause in Germany and to restore deposed princes to their thrones; but more important by far was the fear that, if the German Protestants were finally defeated, the imperialists would turn the Baltic into a Habsburg lake and might perhaps invade Sweden. The Stockholm government therefore desired a settlement that would atomize the empire into a jumble of independent, weak states incapable of threatening the security of Sweden or its hold on the Baltic. Furthermore, to guarantee this fragmentation, Oxenstierna desired the transfer to his country of sovereignty over certain strategic areas of the empire—particularly the duchy of Pomerania on the Baltic coast and the electorate of Mainz on the Rhine.

These, however, were not at all the goals of Sweden's German allies. They aimed rather at the restoration of the prewar situation—in which there had been no place for Sweden—and it soon became clear that they were prepared to make a separate settlement with the emperor in order to achieve it. No sooner was Gustav dead than the elector of Saxony, as "foremost Lutheran prince of the Empire," put out peace-feelers toward Vienna. At first John George (1611–56) was adamant about the need to abolish the Edict of Restitution and to secure a full amnesty for all as preconditions for a settlement; but the imperial victory at Nördlingen made him less demanding. The insistence on an amnesty for Frederick V was dropped, and it was accepted that the edict would be applied in all areas recovered by Catholic forces before November 1627 (roughly speaking, this affected all lands south of the Elbe, but not the Lutheran heartland of Saxony and Brandenburg). The elector might have been required to make even more concessions but for the fact that, over the winter of 1634–35, French troops began to mass along the borders of Germany. As the papal nuncio in Vienna observed: "If the French intervene in Germany, the emperor will be forced to conclude peace with Saxony on whatever terms he can." So the Peace of Prague was signed between the emperor and the Saxons on May 30, 1635, and within a year most other German Lutherans also changed their allegiance from Stockholm to Vienna.

The European war in Germany 1635–45. This partial settlement of the issues behind the war led many in Germany to look forward to a general peace. Certainly the exhaustion of many areas of the empire was a powerful incentive to end the war. The population of Lutheran Württemberg, for example, which was occupied by the imperialists between 1634 and 1638, fell from 450,000 to 100,000; material damage was estimated at 34 million thalers. Mecklenburg and Pomerania, occupied by the Swedes, had suffered in proportion. Even a city like Dresden, the capital of Saxony, which was neither besieged nor occupied, saw its demographic balance change from 121 baptisms for every 100 burials in the 1620s to 39 baptisms for every 100 burials in the 1630s. Amid such catastrophes an overwhelming sense of war-weariness engulfed Germany. The English physician William Harvey (discoverer of the circulation of blood), while visiting Germany in 1636, wrote:

War-weariness in the 1630s

> The necessity they have here is of making peace on any condition, where there is no more means of making war and scarce of subsistence. . . . This warfare in Germany . . . threatens, in the end, anarchy and confusion.

Attempts were made to convert the Peace of Prague into a general settlement. At a meeting of the electors held at Regensburg in 1636–37, Ferdinand II agreed to pardon any prince who submitted to him and promised to begin talks with the foreign powers to discover their terms for peace. But the emperor's death immediately after the meeting ended this initiative. Efforts by Pope Urban VIII (1623–44) to convene a general conference at Cologne were similarly unavailing. Then, in 1640, the new emperor, Ferdinand III (1637–57), assembled the Imperial Diet for the first time since 1613 in order to solve at least the outstanding German problems of the amnesty question and the restitution of church lands. He met with little success and could not prevent first Brandenburg (1641) and then Brunswick (1642) from making a separate agreement with Sweden. The problem was that none of these attempts at peace were acceptable to France and Sweden, yet no lasting settlement could be made without them.

After the Peace of Prague, the nature of the Thirty Years' War was transformed. Instead of being principally a struggle between the emperor and his own subjects, with some foreign aid, it became a war of the emperor against foreign powers whose German supporters were, at most times, few in number and limited in resources. Sweden, as noted above, had distinct and fairly consistent war aims: to secure some bases in the empire, both as guarantees of influence in the postwar era and as some recompense for coming to the rescue of the Protestants, and to create a system of checks and balances in Germany, which would mean that no single power would ever again become dominant. If those aims could be achieved, Oxenstierna was prepared to quit. As he wrote:

> We must let this German business be left to the Germans, who will be the only people to get any good out of it (if there is any), and therefore not spend any more men or money, but rather try by all means to wriggle out of it.

But how could these objectives be best achieved? The Heilbronn League did not long survive the Battle of Nördlingen and the Peace of Prague, and so it became necessary to find an alternative source of support. The only one available was France. Louis XIII and Richelieu, fresh from their triumph in Italy, had been subsidizing Sweden's war effort for some time. In 1635, in the wake of Nördlingen, they signed an offensive and defensive alliance with the Dutch Republic (February 8), with Sweden (April 28), and with Savoy (July 11); they sent an army into the Alps to occupy the Valtelline, a strategic military link between the possessions of the Spanish and Austrian Habsburgs (March); and they mediated a 20-year truce between Sweden and Poland (September 12). Finally, on May 19, 1635, they declared war on Spain.

The aims of France were very different from those of Sweden and its German allies. France wished to defeat Spain, its rival for more than a century, and its early campaigns in Germany were intended more to prevent Ferdinand from sending aid to his Spanish cousins than to impose a Bourbon solution on Germany—indeed, France only declared war on Ferdinand in March 1636. Sweden at first therefore avoided a firm commitment to France, leaving the way clear for a separate peace should the military situation improve sufficiently to permit the achievement of its own particular aims. The war, however, did not go in favour of the allies. French and Swedish forces, operating separately, totally failed to reverse the verdict of Nördlingen: despite the Swedish victory at Wittstock (Oct. 4, 1636) and French gains in Alsace and the middle Rhine (1638), the Habsburgs always seemed able to even up the score. Thus in 1641 Oxenstierna abandoned his attempt to maintain independence and threw in his lot with France. By the terms of the Treaty of Hamburg (March 15, 1641), the two sides promised not to make a separate peace. Instead, joint negotiations with the emperor and the German princes for the satisfaction of the allies' claims were to begin in the Westphalian towns of Münster and Osnabrück. And, while the talks proceeded, the war was to continue.

The Treaty of Hamburg had at last created a coalition capable of destroying the power both of Ferdinand III and of Maximilian of Bavaria. On the whole, France attacked Bavaria, and Sweden fought the emperor; but there was considerable interchange of forces and a carefully coordinated strategy. On Nov. 2, 1642, the Habsburgs' army was routed in Saxony at the Second Battle of Breitenfeld, and the emperor was saved from further defeat only by the outbreak of war between Denmark and Sweden (May 1643–August 1645). Yet, even before Denmark's final surrender, the Swedes were back in Bohemia, and at Jankov (March 6, 1645) they totally destroyed another imperial army. The emperor and his family fled to Graz, while the Swedes advanced to the Danube and threatened Vienna. Reinforcements were also sent to assist the French campaign against Bavaria, and on August 3 Maximilian's forces were decisively defeated at Allerheim.

The Battles of Jankov and Allerheim

Jankov and Allerheim were two of the truly decisive battles of the war, because they destroyed all possibility of the Catholics obtaining a favourable peace settlement. In September 1645 the elector of Saxony made a separate peace with Sweden and so—like Brandenburg and Brunswick before him—in effect withdrew from the war. Meanwhile, at the peace conference in session in Westphalia, the imperial delegation began to make major concessions: Oxenstierna noted with satisfaction that, since Jankov, "the enemy begins to talk more politely and pleasantly." He was confident that peace was just around the corner. He was wrong.

Making peace, 1645–48. One hundred and ninety-four European rulers, great and small, were represented at the Congress of Westphalia, and talks went on constantly from the spring of 1643 until the autumn of 1648. The outstanding issues of the war were solved in two phases: the first, which lasted from November 1645 until June 1647, saw the chief imperial negotiator, Maximilian, Count Trauttmannsdorf, settle most issues; the second, which continued from then until the treaty of peace was signed in October 1648, saw France try to sabotage the agreements already made.

The purely German problems were resolved first, partly because they were already near solution and partly because the foreign diplomats realized that it was best (in the words of Count d'Avaux, the French envoy)

> to place first on the table the items concerning public peace and the liberties of the Empire, . . . because if the German rulers do not yet truly wish for peace, it would be . . . damaging to us if the talks broke down over our own particular demands.

So in 1645 and 1646, with the aid of French and Swedish mediation, the territorial rulers were granted a large degree of sovereignty (*Landeshoheit*), a general amnesty was issued to all German princes, an eighth electorate was created for the son of Frederick V (so that both he and Maximilian possessed the coveted dignity), the Edict of Restitution was finally abandoned, and Calvinism within the empire was granted official toleration. The last two points were the most bitterly argued and led to the division of the German rulers at the Congress into two blocs: the Corpus Catholicorum and the Corpus Evangelicorum. Neither was monolithic or wholly united, but eventually the Catholics split into those who were prepared to make religious concessions in order to have peace and those who were not. A coalition of Protestants and pragmatic Catholics then succeeded in securing the acceptance of a formula that recognized as Protestant all church lands in secular hands by Jan. 1, 1624 (that is, before the gains made by Wallenstein and Tilly), and granted freedom of worship to religious minorities where these had existed by the same date. The Augsburg settlement of 1555 was thus entirely overthrown, and it was agreed that any change to the new formula must be achieved only through the "amicable composition" of the Catholic and Protestant blocs, not by a simple majority.

"Amicable composition"

The amicable composition principle was finally accepted by all parties early in 1648, thus solving the last German problem. That this did not lead to immediate peace was due to the difficulty of satisfying the foreign powers involved. Apart from France and Sweden, representatives from the Dutch Republic, Spain, and many other non-German participants in the war were present, each of them eager to secure the best settlement they could. The war in the Netherlands was the first to be ended: on Jan. 30, 1648, Philip IV of Spain signed a peace that recognized the Dutch Republic as independent and agreed to liberalize trade between the Netherlands and the Iberian world. The French government, led since Richelieu's death (Dec. 4, 1642) by Jules Cardinal Mazarin (Giulio Mazzarino), was bitterly opposed to this settlement, since it left Spain free to deploy all its forces in the Low Countries against France; as a consequence, France devoted all its efforts to perpetuating the war in Germany. Although Mazarin had already signed a preliminary agreement with the emperor in September 1646, which conveyed parts of Alsace and Lorraine to France, in 1647–48 he started a new campaign in Germany in order to secure more. On May 17, 1648, another Bavarian army was destroyed at Zusmarshausen, near Nördlingen, and Maximilian's lands were occupied by the French.

Mazarin's desire to keep on fighting was thwarted by two developments. On the one hand, the pressure of the war on French taxpayers created tensions that in June 1648 erupted into the revolt known as the Fronde. On the other hand, Sweden made a separate peace with the emperor. The Stockholm government, still directed by Oxenstierna, was offered half of Pomerania, most of Mecklenburg, and the secularized bishoprics of Bremen and Verden; it was to receive a seat in the Imperial Diet; and the territories of the empire promised to pay five million thalers to the Swedish army for its wage arrears. With so many tangible gains, and with Germany so prostrated that there was no risk of any further imperial attack, it was clearly time to wriggle out of the war, even without France; peace was thus signed on August 6.

Without Sweden, Mazarin realized that France needed

to make peace at the earliest opportunity. He informed his representatives at the Congress:

> It is almost a miracle that . . . we can keep our affairs going, and even make them prosper; but prudence dictates that we should not place all our trust in this miracle continuing for long.

The final agreements

Mazarin therefore settled with the emperor on easy terms: France gained only the transfer of a bundle of rights and territories in Alsace and Lorraine and little else. Mazarin could, nevertheless, derive satisfaction from the fact that, when the ink dried on the final treaty of Oct. 24, 1648, the emperor was firmly excluded from the empire and was under oath to provide no further aid to Spain. Mazarin settled down to suppress the Fronde revolt and to win the war against Philip IV.

Problems not solved by the war. Some historians have sought to diminish the achievements of the Thirty Years' War, and the peace that ended it, because not all of Europe's outstanding problems were settled. The British historian C.V. Wedgwood, for example, in a classic study of the war first published in 1938, stated baldly:

> The war solved no problem. Its effects, both immediate and indirect, were either negative or disastrous. . . . It is the outstanding example in European history of meaningless conflict.

It is true that the struggle between France and Spain continued with unabated bitterness until 1659 and that, within a decade of the Westphalian settlement, Sweden was at war with Poland (1655–60), Russia (1656–58), and Denmark (1657–58). It is also true that, in the east, a war broke out in 1654 between Poland and Russia that was to last until 1667, while tension between the Habsburgs and the Turks increased until war came in 1663. Even within the empire, there were disputes over the partition of Cleves-Jülich, still a battle zone after almost a half-century, which caused minor hostilities in 1651. Lorraine remained a theatre of war until the duke signed a final peace with France in 1661. But to expect a single conflict in early modern times to have solved all of Europe's problems is anachronistic: the continent was not the single political system that it later became. It is wrong to judge the Congress of Westphalia by the standard of the Congress of Vienna (1815). Examined more closely, the peace conference that ended the Thirty Years' War settled a remarkable number of crucial issues.

Problems solved by the war. The principal Swedish diplomat at Westphalia, Johann Adler Salvius, complained to his government in 1646 that

> people are beginning to see the power of Sweden as dangerous to the balance of power. Their first rule of politics here is that the security of all depends upon the equilibrium of the individuals. When one ruler begins to become powerful . . . the others place themselves, through unions or alliances, into the opposite balance in order to maintain the equipoise.

The new order in Europe

It was the beginning of a new order in Europe, and Sweden, for all her military power, was forced to respect it. The system depended on channeling the aggression of German princes from thoughts of conquering their neighbours to dreams of weakening them; and it proved so successful that, for more than a century, the settlement of 1648 was widely regarded as the principal guarantee of order and peace in central Europe. In 1761 Jean-Jacques Rousseau wrote in praise of the "balance of power" in Europe which, he believed, was anchored in the constitution of the Holy Roman Empire

> which takes from conquerors the means and the will to conquer. . . . Despite its imperfections, this Imperial constitution will certainly, while it lasts, maintain the balance in Europe. No prince need fear lest another dethrone him. The peace of Westphalia may well remain the foundation of our political system for ever.

As late as 1866, the French statesman Alphonse Thiers claimed that

> Germany should continue to be composed of independent states connected only by a slender federative thread. That was the principle proclaimed by all Europe at the Congress of Westphalia.

It was indeed: the balance of power with its fulcrum in Germany, created by the Thirty Years' War and prolonged by the Peace of Westphalia, was a major achievement. It may not have lasted, as Rousseau rashly prophesied, forever, but it certainly endured for more than a century.

It was, for example, almost a century before German rulers went to war with each other again—a strong contrast with the hundred years before 1618, which had been full of armed neutrality and actual conflict. The reason for the contrast was simple: the Thirty Years' War had settled both of the crises which had so disturbed the peace in the decades before it began.

In the lands of the Austrian Habsburgs, there were now no powerful estates and no Protestant worship (except in Hungary), and, despite all the efforts of the Swedish diplomats at Westphalia, there was no restoration of the lands confiscated from rebels and others. The Habsburg Monarchy, born of disparate units but now entirely under the authority of the king-emperor, had become a powerful state in its own right. Purged of political and religious dissidents and cut off from its western neighbours and from Spain, the compact private territories of the Holy Roman emperor were still large enough to guarantee him a place among the foremost rulers of Europe. In the empire, by contrast, the new stability rested upon division rather than unity. Although the territorial rulers had acquired, at Westphalia, supreme power in their localities and collective power in the Diet to regulate common taxation, defense, laws, and public affairs without imperial intervention, the "amicable composition" formula prevented in fact any changes being made to the status quo. The originality of this compromise (enshrined in Article V, paragraph 52, of the Instrumentum Pacis Osnabrugense) has not always been appreciated. An age that normally revered the majority principle sanctioned an alternative method—parity between two unequal groups (known as *itio in partes*)—for reaching decisions.

Looked at more pragmatically, what the *itio in partes* formula achieved was to remove religion as a likely precipitant of political conflict. Although religion remained a matter of high political importance (for instance, in cementing an alliance against Louis XIV after 1685 or in unseating James II of England in 1688), it no longer determined international relations as it once had done.

The secularization of European politics

When one of the diplomats at the Congress of Westphalia observed that "reason of state is a wonderful animal, for it chases away all other reasons," he in fact paid tribute to the secularization that had taken place in European politics since 1618. But when, precisely, did it happen? Perhaps with the growing preponderance of non-German rulers among the enemies of the emperor. Without question, those German princes who took up arms against Ferdinand II were strongly influenced by confessional considerations, and, as long as these men dominated the anti-Habsburg cause, so too did the issue of religion. Frederick of the Palatine and Christian of Anhalt, however, failed to secure a lasting settlement. Gradually the task of defending the Protestant cause fell into the hands of Lutherans, less militant and less intransigent than the Calvinists; and the Lutherans were prepared to ally, if necessary, with Anglican England, Catholic France, and even Orthodox Russia in order to create a coalition capable of defeating the Habsburgs. Naturally such states had their own reasons for fighting; and, although upholding the Protestant cause may have been among them, it seldom predominated. After 1625, therefore, the role of religious issues in European politics steadily receded. This was, perhaps, the greatest achievement of the war, for it thus eliminated the major destabilizing influence in European politics, which had both undermined the internal cohesion of many states and overturned the diplomatic balance of power created during the Renaissance. (N.G.P.)

The great age of monarchy, 1648–1789

ORDER FROM DISORDER

By the 17th century there was already a tradition and awareness of Europe: a reality stronger than that of an area bounded by sea, mountains, grassy plains, steppes, or deserts where Europe clearly ended and Asia began—"that geographical expression" which in the 19th century Otto von Bismarck was to see as counting for little against

the interests of nations. In the two centuries before the French Revolution and the triumph of nationalism as a divisive force, Europe exhibited a greater degree of unity than appeared on the mosaic of its political surface. With appreciation of the separate interests that Bismarck would identify as "real" went diplomatic, legal, and religious concerns which involved states in common action and contributed to the notion of a single Europe. King Gustav II Adolf of Sweden saw one aspect when he wrote: "All the wars that are afoot in Europe have become as one."

A European identity took shape in the work of Hugo Grotius, whose *De Jure Belli et Pacis* (1625; *On the Law of War and Peace*) was a plea for the spirit of law in international relations. It gained substance in the work of the great congresses (starting with those of Münster and Osnabrück before the Peace of Westphalia in 1648) that met not only to determine rights and frontiers, taking into account the verdict of battle and resources of states, but also to settle larger questions of justice and religion.

The idea of Europe

By 1700 statesmen had begun to speak of Europe as an interest to be defended against the ambitions of particular states. Europe represented an audience for those who wrote about the great issues of faith, morals, politics, and, increasingly, science: Descartes did not write only for Frenchmen, nor Leibniz for Germans. The use of Latin as the language of diplomacy and scholarship and the ubiquity, alongside local systems and customs, of Roman law were two manifestations of the unity of Christendom.

As a spiritual inheritance and dynamic idea greater than the sum of the policies of which it was composed, "Christendom" best represents Europe as envisaged by those who thought and wrote about it. The existence of vigorous Jewish communities—at times persecuted, as in Poland in 1648, but in places such as Amsterdam secure, prosperous, and creative—only serves to emphasize the essential fact: Europe and Christendom were interchangeable terms. The 16th century had experienced schism, and the development of separate confessions had shredded "the seamless robe," but it had done so without destroying the idea of catholicism to which the Roman church gave institutional form. The word *catholic* survived in the creeds of Protestant churches, such as that of England. Calvin had thought in catholic, not sectarian, terms when he mourned for the Body of Christ, "bleeding, its members severed." Deeper than quarrels about articles of belief or modes of worship lay the mentality conditioned by centuries of war against pagan and infidel, as by the Reconquista in Spain, which had produced a strong idea of a distinctive European character. The Renaissance, long-evolving and coloured by local conditions, had promoted attitudes still traceable to the common inheritance. The Hellenic spirit of inquiry, the Roman sense of order, and the purposive force of Judaism had contributed to a cultural synthesis and within it an article of faith whose potential was to be realized in



Europe in 1648.

the intellectual revolution of the 17th century—namely, that man was an agent in a historical process which he could aspire both to understand and to influence.

By 1600 the outcome of that process was the complex system of rights and values comprised in feudalism, chivalry, the crusading ideal, scholasticism, and humanism. Even to name them is to indicate the rich diversity of the European idea, whether inspiring adventures of sword and spirit or imposing restraints upon individuals inclined to change. The forces making for change were formidable. The Protestant and Roman Catholic Reformations brought passionate debate of an unsettling kind. Discoveries and settlement overseas extended mental as well as geographic horizons, brought new wealth, and posed questions about the rights of indigenous peoples and Christian duty toward them. Printing gave larger scope to authors of religious or political propaganda. The rise of the state brought reactions from those who believed they lost by it or saw others benefit exceedingly from new sources of patronage.

Meanwhile, the stakes were raised by price inflation, reflecting the higher demand attributable to a rise in the population of about 25 percent between 1500 and 1600 and the inflow of silver from the New World; the expansion of both reached a peak by 1600. Thereafter, for a century, the population rose only slightly above 100 million and pulled back repeatedly to that figure, which seemed to represent a natural limit. The annual percentage rate of increase in the amount of bullion in circulation in Europe, which had been 3.8 in 1550 and 1 in 1600, was, by 1700, 0.5. The extent to which these facts, with attendant phenomena—notably the leveling out from about 1620, and thereafter the lowering, of demand, prices, and rents before the resumption of growth about 1720—influenced the course of events must remain uncertain. Controversy has centred around the cluster of social, political, and religious conflicts and revolts that coincided with the deepening of the recession toward mid-century. Some historians have seen there not particular crises but a "general crisis."

The "general crisis" theory

Giraudon/Art Resource, New York City



Engraving by Pierre Le Pautre showing the orderly, geometric plan of the gardens at Versailles, designed by André Le Nôtre and begun in 1660. In the Bibliothèque municipale, Versailles, Fr.

Most influential in the debate have been the Marxist view that it was a crisis of production and the liberal political view that it was a general reaction to the concentration of power at the centre.

Any single explanation of the general crisis may be doomed to fail. That is not to say that there was no connection between different features of the period. These arose from an economic malaise that induced an introspective mentality, which tended to pessimism and led to repressive policies but which also was expressed more positively in a yearning and search for order. So appear rationalists following René Descartes in adopting mathematical principles in a culture dominated by tradition; artists and writers accepting rules such as those imposed by the French Academy (founded 1635); statesmen looking for new principles to validate authority; economic theorists (later labeled "mercantilists") justifying the need to protect and foster native manufactures and fight for an apparently fixed volume of trade; the clergy, Catholic and Protestant alike, seeking uniformity and tending to persecution; witch-hunters rooting out irregularities in the form of supposed dealings with Satan; even gardeners trying to impose order on unruly nature. Whether strands in a single pattern or distinct phenomena that happen to exhibit certain common principles, each has lent itself to a wider perception of the 17th century as classical, baroque, absolutist, or mercantilist.

There is sufficient evidence from tolls, rents, taxes, riots, and famines to justify arguments for something more dire than a downturn in economic activity. There are, however, other factors to be weighed: prolonged wars fought by larger armies, involving more matériel, and having wider political repercussions; more efficient states, able to draw more wealth from taxpayers; and even, at certain times (such as the years 1647–51), particularly adverse weather, as part of a general deterioration in climatic conditions. There are also continuities that cast doubt on some aspects of the general picture. For example, the drive for conformity can be traced at least to the Council of Trent, whose final sessions were in 1563; but it was visibly losing impetus, despite Louis XIV's intolerant policy leading to the revocation of the Edict of Nantes (1685), after the Peace of Westphalia. Puritanism, which has been seen as a significant reflection of a contracting economy, was not a prime feature of the second half of the century, though mercantilism was. Then there are exceptions even to economic generalizations: England and, outstandingly, the United Provinces of the Netherlands. Insights and perspectives gain from the search for general causes. But truth requires an untidy picture of Europe in which discrepancies abound, in which men subscribe to a common civilization while cherishing specific rights; in which countries evolved along distinctive paths; and in which much depended on the idiom of a community, on the ability of ruler or minister, on skills deployed and choices made.

Complementing the search for order and for valid authority in other fields, and arising out of the assertion of rights and the drive to control, a feature of the 17th century was the clarification of ideas about the physical bounds of the world. In 1600 "Europe" still lacked exact political significance. Where, for example, in the eastern plains before the Ural Mountains or the Black Sea were reached, could any line have meaning? Were Christian peoples—Serbs, Romanians, Greeks, or Bulgarians—living under Turkish rule properly Europeans? The tendency everywhere was to envisage boundaries in terms of estates and lordships. Where the legacy of feudalism was islands of territory either subject to different rulers or simply independent, or where, as in Dalmatia or Podolia (lands vulnerable to Turkish raids), the frontier was represented by disputed, inherently unstable zones, a linear frontier could emerge only out of war and diplomacy. The process can be seen in the wars of France and Sweden. Both countries were seen by their neighbours as aggressive, yet they were concerned as much with a defensible frontier as with the acquisition of new resources. Those objectives inspired the expansionist policies of Richelieu, Mazarin, and Louis XIV and—with the added incentives of fighting

the infidel and recovering a patrimony lost since the defeat at Mohács in 1526—the reconquest of Hungary, which led to the Treaty of Carlowitz (1699). The frontier then drawn was sufficiently definite—despite modifications, as after the loss of Belgrade (1739)—to make possible effective government within its perimeter.

Another feature of the period was the drawing into the central diplomatic orbit of countries that had been absorbed hitherto in questions of little consequence. Although Henry of Valois had been elected king of Poland before he inherited the French throne (1574) and James VI of Scotland (later James I of England, 1603–25) had married Anne of Denmark, whose country had a footing in Germany through its duchy of Holstein, it was still usual for western statesmen to treat the Baltic states as belonging to a separate northern system. Trading interests and military adventures that forged links, for example, with the United Provinces—as when Sweden intervened in the German war in 1630—complicated already tangled diplomatic questions.

Travelers who ventured beyond Warsaw, Kraków, and the "black earth" area of Mazovia, thence toward the Pripet Marshes, might not know when they left Polish lands and entered those of the tsar. The line between Orthodox Russia and the rest of Christian Europe had never been so sharp as that which divided Christendom and Islām. Uncertainties engendered by the nature of Russian religion, rule, society, and manners perpetuated former ambivalent attitudes toward Byzantium. Unmapped spaces, where Europe petered out in marshes, steppes, and forests of birch and alder, removed the beleaguered though periodically expanding Muscovite state from the concern of all but neighbouring Sweden and Poland. The establishment of a native dynasty with the accession of Michael Romanov in 1613, the successful outcome of the war against Poland that followed the fateful revolt in 1648 of the Ukraine against Polish overlordship, the acquisition of huge territories including Smolensk and Kiev (Treaty of Andrusovo, 1667), and, above all, the successful drive of Peter I the Great to secure a footing in the Baltic were to transform the picture. By the time of Peter's death in 1725, Russia was a European state: still with some Asian characteristics, still colonizing rather than assimilating southern and eastern lands up to and beyond the Urals, but interlocked with the diplomatic system of the West. A larger Europe, approximating to the modern idea, began to take shape.

THE HUMAN CONDITION

Population. For most inhabitants of Europe, the highest aim was to survive in a hazardous world. They were contained in an inelastic frame by their inability to produce more than a certain amount of food or to make goods except by hand or by relatively simple tools and machines. In this natural, or preindustrial, economy, population played the main part in determining production and demand through the amount of labour available for field, mill, and workshop and through the number of consumers. Jean Bodin (writing toward the end of an age of rising population) stated what was to become the truism of the anxious 17th century when he wrote that men were "the only strength and wealth." The 16th century had seen the last phase in recovery from the Black Death, which had killed about a third of Europe's people. The 1590s brought a sharp check: dearth and disorder were especially severe in France and Spain. There were particular reasons: the effect of civil wars and Spanish invasion in France, the load placed on the Castilian economy by the imperialist policies of Philip II. France made a speedy, if superficial, recovery during the reign of Henry IV, but the truce between Spain and the United Provinces (1609) presented the Dutch with an open market from which they proceeded to drive out the native producers. Meanwhile, virulent outbreaks of plague had contributed to Spain's loss of more than a million people.

Effects of agricultural depression

A feature of the late 16th century had been the growth of cities. Those that had flourished most from expansion of trade or government offered sustenance of a kind for refugees from stricken villages. Meanwhile, peasants were paying the price for the intensified cultivation necessitated by the 16th century's growth in population. The subdivision of holdings, the cultivation of marginal land, and the inevitable preference for cereal production at the cost of grazing, with consequent loss of the main fertilizer, animal dung, depressed crop yields. The nature of the trap that closed around the poor can be found in the statistics of life expectancy, averaging 25 years but nearer 20 in the larger towns. It took three times as many births to maintain the level of population as it did at the end of the 20th century.

There also were large fluctuations, such as that caused by the loss of at least 5 of Germany's 20 million during the Thirty Years' War. The "vital revolution" is an apt description of the start of a process that has continued to the present day. Until 1800, when the total European population was about 180 million, growth was modest and uneven: relatively slow in France (from 20 to 27 million), Spain (from 7 to 9 million), and Italy (from 13 to 17 million) and nonexistent in war-torn Poland until 1772, when the first of three partitions anticipated its demise as a political entity. Significantly, the rise in population was the most marked in Britain, where agriculture, manufacturing, and trade benefited from investment and innovation, and in Russia, which was technologically backward but which colonized near-empty lands. Among the causes were improvements in housing, diet, and hygiene.

Climate. Given man's dependence on nature, the deterioration of the climate during the Little Ice Age of the 17th century should be considered as a demographic factor. The absence of sunspots after 1645 was noted by astronomers using the recently invented telescope; the aurora borealis (caused by high-energy particles from the Sun entering the Earth's atmosphere) was so rarely visible that it was thought ominous when it did appear; measurement of tree rings shows them to be relatively thin in this period but containing heavy deposits of radioactive carbon-14, associated with the decline of solar energy; snow lines were observed to be lower; and glaciers advanced into Alpine valleys, reaching their farthest point about 1670. All of these phenomena support plentiful anecdotal evidence for a period of unfavourable climate characterized by cold winters and wet summers. A decrease of about 1 percent in solar radiation meant a growing season shorter by three weeks and the altitude at which crops would ripen lowered by 500 feet. With most of the population living near subsistence level and depending upon cereal crops, the effect was most severe on those who farmed marginal land, especially on northerners for whom the growing season was already short. They were not the only ones who suffered, for freakish conditions were possible then as now. Around Toledo—where until the late 17th century the plains and sierras of New Castile provided a bare living from wheat, vines, and olives—disastrous frosts resulted in mass emigration. Drought also brought deprivation. During 1683 no rain fell in Andalusia until November; the cattle had to be killed, the crops were dry stalks, and thousands starved. In the great winter of 1708–09, rivers froze, even the swift-flowing Rhône, and wolves roamed the French countryside; after late frosts, which killed vines and olive trees, the harvest was a catastrophe: by December the price of bread had quadrupled.

Demographic and political effects of climate

Less spectacular, but more deadly, were the sequences of cold springs and wet summers. From the great mortalities such as those of 1647–52 and 1691–95 in France the population was slow to recover; women were rendered infertile, marriages were delayed, and births were avoided. They were times of fear for masters and shameful resort to beggary, abortion, and infanticide for the common people. It was also a hard time for the government and its tax-collectors. The disastrous harvest of the previous year was the direct cause of the revolt of the Sicilians in 1648. The connection between the outbreak of the Fronde in the same year and harvest failure is less direct: some revolt would probably have occurred in any case. There is a clear link, however, between the wet Swedish summer of 1649 and the constitutional crisis of the following year.

War. The period between the revolt of Bohemia (1618) and the peace of Nystad (1721), which coincides with the check to growth and subsequent recession, also saw pro-

longed warfare. Developments within states and leagues between them made possible the mustering of larger armies than ever before. How important then was war as an influence on economic and social conditions? The discrepancy between the high aspirations of sovereigns and the brutal practice of largely mercenary soldiers gave the Thirty Years' War a nightmarish character. It is, however, hard to be precise about the consequences of this general melee. As hostilities ended, rulers exaggerated losses to strengthen claims for compensation; refugees returned, families emerged from woods and cellars and reappeared on tax rolls; ruined villages were rebuilt and wastelands were tilled; a smaller population was healthier and readily procreative. The devastation was patchy. Northwestern Germany, for example, was little affected; some cities, such as Hamburg, actually flourished, while others, such as Leipzig and Nürnberg, quickly responded to commercial demand. The preindustrial economy proved to be as resilient as it was vulnerable. Yet the German population did not rise to prewar levels until the end of the 17th century.

The causes of this demographic disaster lie in the random nature of operations and the way in which armies, disciplined only on the battlefield, lived off the land. Casualties in battle were not the prime factor. In the warfare of the 17th and 18th centuries, mortal sickness in the armies exceeded death in action in the proportion of five to one. Disease spread in the camps and peasant communities deprived by pillage of their livelihood. The cost to the home country of operations abroad could be comparatively small, as it was to Sweden, at least until 1700 and the Great Northern War, which developed into a struggle for survival. Special factors—notably naval and commercial strength, the ability to prey on the enemy's commerce and colonies, and immigration from the occupied south—enabled the United Provinces to grow richer from their wars against Spain (1572–1609 and 1621–48). By contrast, those living in the main theatres of war and occupation were vulnerable: the Spanish southern provinces of the Netherlands, Lorraine (open to French troops), Pomerania and Mecklenberg (to Swedish troops), and Württemberg (to Austrian and French) were among those who paid the highest bills of war.

The ability of states to bring their armies under control meant that operations after 1648 were better regulated and had less effect on civilians. Lands were ravaged deliberately to narrow a front or to deprive the enemy of base and food: such was the fate of the Palatinate, sacked by the French under Marshall René Tessé in 1689. Meanwhile, warfare in the north and east continued to be savage, largely unrestrained by conventions that were gaining hold in the west. The war of the Spanish Succession (1701–14) ran parallel with the Great Northern War (1700–21) and the war of Austria (allied with Venice and sometimes Poland) against the Turks, which had begun with the relief of Vienna in 1683 and continued intermittently until the peace of Passarowitz in 1718. In brutal campaigning over the plains of Poland and Hungary, the peasants were the chief sufferers. For the Hungarians, long inured to border war, liberation by the Habsburgs meant a stricter landowning regime. In one year, 1706, the Swedes gutted 140 villages on the estates of one of Augustus II's followers. The Russians never subscribed to the stricter rules that were making western warfare look like a deadly game of chess. The later years of Frederick the Great were largely devoted to the restoration of Prussia, despoiled during the Russian occupation of 1760–62.

Early 18th-century wars

Such exceptions apart, it seems that most people were little affected by military operations after 1648. The Flemish peasant plowed the fields in peace within miles of Marlborough's encampments; his uniformed troops received regular pay and looting was punished. That was the norm for armies of the 18th century. This improvement was a factor in the rise of population in that century, but not the main one. At worst, war only exacerbated the conditions of an underdeveloped society.

Health and sickness. By the dislocation of markets and communications and the destruction of shipping, and by diverting toward destructive ends an excessive proportion of government funds, war tended to sap the wealth of the community and narrow the scope for governments and individuals to plan and invest for greater production. The constructive reforms of the French statesman Jean-Baptiste Colbert in the 1660s, for example, would have been unthinkable in the 1640s or '50s; they were checked by the renewal of war after 1672 and were largely undone by the further sequence of wars after his death. War determined the evolution of states, but it was not the principal factor affecting the lives of people. Disease was ever present, ready to take advantage of feeble defense systems operating without the benefit of science. The 20th-century French historian Robert Mandrou wrote of "the chronic morbidity" of the entire population. There is plenty of material on diseases, particularly in accounts of symptoms and "cures," but the language is often vague. Christian of Brunswick was consumed in 1626 "by a gigantic worm"; Charles II of Spain, dying in 1700, was held to be bewitched; men suffered from "the falling sickness" and "distemper."

There are no reliable statistics about height and weight. It is difficult even to define what people regarded as normal good health. The average person was smaller than today. Even if courtiers flattered Louis XIV, deemed to be tall at five feet four inches, the evidence of portraits and clothes shows that a Frenchman of six feet was exceptionally tall; the same goes for most southern and central Europeans. Scandinavians, Dutch, and North Germans were generally larger; protein in meat, fish, and cheese was probably as important as their racial stock. Even where there were advances in medicine, treatment of illness remained primitive. The majority who relied on the simples or charms of the local wise woman may have been no worse off than those for whom more learned advice was available. Court doctors could not prevent the death of the Duke de Bourgogne, his wife, and his eldest son in 1712 from what was probably scarlet fever; the younger son, the future Louis XV, may have been saved by his nurse's removing him from their ministrations.

The work of William Harvey, concerning the circulation of the blood; of Antonie van Leeuwenhoek, observing through his microscope blood circulating in minute capillaries or spermatozoa in water; of Francesco Redi, developing by experiment (in a book of 1668) Harvey's principle that "all living things come from an egg"; or of Hermann Boerhaave, professor of chemistry, medicine, and botany at Leiden, carrying out public dissections of human bodies, reveals the first approaches to modern knowledge and understanding. A striking example of what could be achieved was the efficacy of vaccine against the rampant smallpox after the discoveries of Edward Jenner and others, but vaccination was not much used until the beginning of the 19th century. As in other scientific fields, there was a long pause between pioneering research and regular practice. Trained by book, taking no account of organic life, envisaging illness as a foreign element lodged in the sick person's body, even tending to identify disease with sin, doctors prescribed, dosed, and bled, leaning on pedantic scholarship blended with primitive psychology. Therapy was concerned mainly with moderating symptoms. For this purpose mercury, digitalis, ipecac root, and, especially, opium were used; the latter was addictive but afforded relief from pain. The wisest navigators in this frozen sea were those who knew the limitations of their craft, like William Cullen, an Edinburgh physician who wrote: "We know nothing of the nature of contagion that can lead us to any measures for removing or correcting it. We know only its effects."

Causes of morbidity

To peer in imagination into the hovels of the poor or to walk down streets with open drains between houses decayed into crowded tenements, to visit shanty towns outside the walls, such as London's Bethnal Green or Paris' Faubourg Saint-Marcel, to learn that the latter city's great open sewer was not covered until 1740, is to understand why mortality rates among the poor were so high. In town and country they lived in one or two rooms, often under the same roof as their animals, sleeping on straw, eating with their fingers or with a knife and spoon, washing infrequently, and tolerating lice and fleas. Out-

side, dung and refuse attracted flies and rodents. Luckier people, particularly in the north, might have had glass in their windows, but light was less important than warmth. In airless rooms, thick with the odours of dampness, defecation, smoke, and unwashed bodies, rheumatic or bronchial ailments might be the least of troubles. Deficient diet in childhood could mean rickety legs. Crude methods of delivery might cause permanent damage to both mothers and children who survived the attentions of the local midwife. The baby who survived (one in four died in the first year of life) was launched on a hazardous journey.

Some diseases, such as measles, seem to have been more virulent then than now. Typhus, spread by lice and fleas, and typhoid, waterborne, killed many. Tuberculosis was less common than it was to become. Cancer, though hard to recognize from contemporary accounts, was certainly rare: with relatively little smoking and with so many other diseases competing for the vulnerable body, that is not surprising. There were few illnesses, mental or physical, of the kind today caused by stress. Alcoholism was less common, despite the increase in the drinking of spirits that debauched city dwellers: cheap gin became a significant social problem in William Hogarth's London. Abnormalities resulting from inbreeding were frequent in mountain valleys or on remote coasts.

Syphilis had been a growing menace since its introduction in the 16th century, and it was rife among prostitutes and their patrons: it was a common cause of blindness in children. Women, hapless victims of male-dominated morality, were frequently denied the chance of early mercury treatment because of the stigma attached to the disease. Scrofula, a gangrenous tubercular condition of the lymph glands, was known as "the king's evil" because it was thought to be curable by the king's touch: Louis XIV practiced the ceremony conscientiously. Malaria was endemic in some swampy areas. Though drainage schemes were taken up by enlightened sovereigns, prevention awaited inexpensive quinine. Nor could doctors do more than let smallpox take its course before the general introduction of vaccines. The plague, chiefly an urban disease that was deadliest in summer and dreaded as a sentence of death, could be combated only by measures of quarantine such as those enforced around Marseille in 1720, when it made its last appearance in France. Its last European visitation was at Messina in 1740. Deliverance from plague was not the least reason for Europeans of the Enlightenment to believe that they were entering a happier age.

Poverty. Though its extent might vary with current economic trends, poverty was a constant state. It is hard to define since material expectations vary among generations, social groups, and countries. If those with sufficient land or a wage large enough to allow for the replacement of tools and stock are held to be above the poverty line, then at least a quarter of Europe's inhabitants were below it. They were the *bas peuple* whom the French engineer Sébastien Le Prestre de Vauban observed in the 1690s, "three-fourths of them . . . dressed in nothing but half-rotting, tattered linen"; a century later the philosopher the Marquis de Condorcet described those who "possess neither goods nor chattels [and are] destined to fall into misery at the least accident." That could be illness or injury to a breadwinner, the failure of a crop or death of a cow, fire or flood, or the death or bankruptcy of an employer. Sometimes poverty showed itself in a whole community demoralized through sickness—as by malaria in Italy's Pontine Marshes and goitre in Alpine valleys—or through the sapping of vitality when the young left to find work. Factors could be the unequal struggle with a poor soil or the exactions of a landowner: so the agricultural writer Arthur Young, at Combourg, wondered that the seigneur, "this Monsieur de Chateaubriant, . . . has nerves strung for such a residence amidst such filth and poverty." Many were victims of an imprisoning socioeconomic regime, such as Castilian latifundia or Polish serfdom. A trade depression, a change of fashion, or an invention that made traditional manufacturing obsolete could bring destitution to busy cities such as Leiden, Lyon, Florence, or Norwich or to specialized communities such as the silk weavers of 18th-century England's Spitalfields.

Fragility of a subsistence economy

Taxes, on top of rents and dues, might be the decisive factor in the slide from sufficiency to destitution. A member of the Castilian Cortes of 1621 described the results: "Numerous places have become depopulated and disappeared from the map. . . . The vassals who formerly cultivated them now wander the roads with their wives and children." Some had always been beyond the reach of the collector of taxes and rents, such as the *bracchianti* (day labourers) described by a Mantuan doctor as "without a scrap of land, without homes, lacking everything except a great brood of children . . . with a humble train of a few sheep and baggage consisting of a tattered bedstead, a mouldy cask, some rustic tools and a few pots and pans."

Moneylenders were pivotal figures in village society. In southern Italy, merchants advanced money on wheat in *contratti alla voce* (oral agreements). The difference between the arranged price and that at harvest time, when the loan was repaid, represented their profit. Throughout Europe, land changed hands between lender and borrower: foreclosure and forfeit is an aspect of primitive capitalism often overlooked in the focus on trade and manufacturing. Society, even in long-settled areas, revealed a constant flux. As the 20th-century French historian Marc Bloch pointed out, hierarchy was always present in some degree, even in districts where sharecropping meant dependence on the owner's seed and stock. In the typical village of western Europe, there were gradations between the well-to-do farmer, for whom others worked and whose strips would grow if he continued to be thrifty, and the day labourer, who lived on casual labour, hedging, ditching, thatching, repairing terraces, pruning vines, or making roads.

Urban poverty posed the biggest threat to governments. The situation became alarming after 1750 because the rise in population forced food prices up, while the employers' advantage in the labour market depressed wages. Between 1730 and 1789, living costs in France rose by 62 percent; in Germany the price of rye for the staple black bread rose by up to 30 percent while wages fell. In Italian cities the poor depended on the authorities' control of markets, prices, and food supplies. The riots of Genoa in 1746 show what was liable to happen if they failed. The causes of riots varied. In England, in 1766, grievances included the Irish, Roman Catholics, the press-gang, and gin taxes. The source was almost invariably poverty measured against a vague conception of a "fair wage," fanned by rumours about hoarding and the creating of false prices. Paris was not uniquely dangerous. Before 1789, when the fury of the mob acquired political importance, the Gordon Riots (1780) had shown the way in which London could be taken over by a mob. The problem originated in rural poverty. Improvements in agriculture, such as enclosure, did not necessarily provide more work. Where there were no improvements or old abuses continued—such as the short-term leases of southern Italy, which encouraged tenants to over-crop and so exhaust the soil—the city provided the only hope. Naples, with the greatest profusion of beggars in the streets, was the most swollen of cities: at 438,000 in 1797, the population had risen by 25 percent in 30 years.

The typical relationship of mutual support was between poor hill country and large town; Edinburgh or Glasgow provided support for the Scots Highlanders, Vienna or Marseille for the Alpine poor. In Marseille a settled population of 100,000 supported 30,000 immigrants. Younger sons from the European fringes went for bread to the big armies: Croats to the Austrian, Finns to the Swedish, Scots and Irish everywhere. Women were usually left behind with the old men and children to look after the harvest in areas of seasonal migration. Domestic service drew many girls to towns with a large bourgeois population. Certain other occupations, notably lacemaking, were traditionally reserved for women. Miserably paid, young Frenchwomen risked their eyesight in fine work to earn enough for dowry and marriage. In a society where contraception was little known, except through abstinence, and irregular liaisons were frowned upon, the tendency to marry late was an indication of poverty. Almost half the women of western Europe married after 25; between 10 and 15 percent did not marry at all. The prevalence of abortion and infanticide is painfully significant: it was clearly not confined to

unmarried couples. In 18th-century Brussels, more than 2,000 babies were abandoned annually to be looked after by charitable institutions. Repairs to a drain in Rennes in the 1720s revealed the tiny skeletons of 50 babies. Every major city had large numbers of prostitutes. There were approximately 20,000 in Paris, and, more surprisingly, in staid, episcopally governed Mainz, it was estimated that a third of the women in the poorer districts were prostitutes. Victims and outcasts, with the beggars and derelicts of crowded tenements, they helped create the amoral ambience in which criminals could expect tolerance and shelter.

Crime

Naturally associated with poverty, crime was also the product of war, even the very maintenance of armies. Desertion led to a man's living an outlaw's life. Despite ferocious penalties (having the nose and one ear cut off) the Prussian army lost 30,000 deserters between 1713 and 1740. The soldier's life might not equip a man for settled work. It was hard, in unsettled times, to distinguish between overtly treasonous acts, as of leaders in revolts, and the persistent banditry that accompanied and outlasted them. Another gray area surrounded the arbitrary actions of officials—for example, billeting troops, sometimes, as in the *dragonnades* employed by Louis XIV against the Huguenots, for political reasons. Tax collection often involved violence and chicanery. The notorious Mandrin, whose prowess Tobias Smollett recorded, had also been a tax collector. Leader of a gang of some 500, he used his knowledge of the system to construct a regime of extortion. Eventually betrayed and broken on the wheel, he remained a local hero.

Banditry was a way of life on the Cossack and Balkan marches, but it was not only there that roads were unsafe. Barred by magistrates from the towns, gangs of beggars terrorized country districts. Children, pursuing victims with sorry tales, were keen trainees in the school of crime, picking pockets, cutting horsetails, soliciting for "sisters," and abetting smuggling. The enlargement of the role of the state, with tariffs as the main weapon in protectionist strategies, encouraged evasion and smuggling. Just as few country districts were without robbers, few coasts were without smuggling gangs. A Norman seaman could make more by one clandestine Channel crossing than by a year's fishing. Only the approval of the poor could make romantic figures of such criminals as Dick Turpin or Marion de Fouet.

The savagery of punishments was in proportion to the inadequacy of enforcement. To traditional methods—hanging, dismemberment, flogging, and branding—the possession of colonies added a new resort toward the end of the 18th century, that of transportation. By then, notably in the German and Italian lands of the Habsburg brothers Joseph II and Leopold II, who were influenced by arguments of reason and humanity, crime was fought at the source by measures to liberate trade, moderate punishments, and increase provision for the poor.

A central theme in Christian teaching was the blessed state of the poor. Holy poverty was the friars' ideal; ardent reformers ensured that some returned to it. The ascetic Father Joseph, personal agent of Cardinal Richelieu, and Abraham Sancta Clara, preacher at the court of Leopold I, were representative figures. With the acceptance of poverty went awareness of a Christian's duty to relieve it. Alms for the poor figured largely in wills and were a duty of most religious orders. Corporate charity had a larger place in Counter-Reformation Catholicism than in the thinking of Protestants, who stressed private virtues and endowments.

Relief for the poor

The secularization of church property that accompanied the Reformation reduced levels of relief. However, meticulous church elders in Holland and parish overseers in England were empowered to raise poor rates. In Brandenburg a law of 1696 authorized parishes to provide work for the deserving poor and punishment for others. In Denmark the government pronounced in 1683 that the pauper had the legal right to relief: he could work in land reclamation or road building. Different was the approach of Vincent de Paul (1581–1660), whose instructions to the Sisters of Charity, founded to help "our lords the poor," were both compassionate and practical. His idea of the *hôpital général*, a privately funded institution for the aged, crippled, and orphaned, was taken over in 1662: an edict commended the institution of *hôpitaux* throughout the land. Care for the poor was tinged with concern for their souls: beggars and prostitutes were carefully segregated.

With emphasis on the rights of the individual, the French Revolution did not lead to improvement in poor relief but to the reverse. Nor was the record of the Enlightenment impressive in this area. Impatient with tradition and anticlerical, the philosophes tended to be more fluent in criticism of existing systems than practical in proposals for better ones. The new breed of economists, the physiocrats, were opposed to any interference with the laws of nature, especially to any support that did not show a productive return. The threat of social disorder did alarm the upper class, however, and contributed to the revival in Britain of Evangelical religion, which stressed elementary education for the poor, reform of prisons, and abolition of the slave trade and slavery. Meanwhile, the Holy Roman emperor Joseph II had harnessed new funds for orphanages, hospitals, medical schools, and special institutions for the blind and the insane. In 1785 the Vienna General Hospital had 2,000 beds. There was provision for deprived children of all sorts. Graduated charges and free medical care for paupers were among features of a policy that represented the utilitarian spirit at its most humane.

THE ORGANIZATION OF SOCIETY

Corporate society. The political history of Europe is inevitably the history of privileged minorities. In states of the eastern and northern fringes, "the political nation"—comprising those individuals who had some notion of loyalties beyond the parish and civil duties, if only at a local level, at the occasional diet, or in the army—hardly extended beyond the ranks of the gentry. Where they were numerous (a tenth of the population in Poland, for example), many would maintain themselves as clients of a magnate; even when theoretically independent, they would be likely to envisage the state in terms of sectional interest. The political life of England and Holland and the growing administration of France, Spain, and some German states opened doors to more sophisticated citizenship. Generally, however, political concerns were beyond the ken of peasants or ordinary townspeople for whom the state existed remotely, in the person of the prince, or directly, in that of the tax collector or billeting officer. It does not follow that it is futile to portray the people as a whole. First, however, it is necessary to identify certain characteristics of their world.

It was a Christian society which accepted, in and over the animist world where magic held many in thrall, the sovereignty of God and his laws. A priest might use folklore to convey the Christian message and expect allegiance so long as he endorsed paramount loyalties to family and parish. He might lose them if he objected too strongly to vendetta, charivari, and other forms of collective violence or simply to his parishoners' preference for tavern over church. Catholic or Protestant, he might preach against superstition, but he was as likely to denounce the witch as to curb her persecutors. He might see no end to his war against ignorance and sin; and he might falter in assurance of the love of God for suffering humanity. No more than any layperson was he immune to doubt and despair. But the evidence is unambiguous: the framework was hardly shaken. It was Christian doubt or Christian pessimism, all under the judgment of God. The priest in the confessional or the Protestant minister, Bible in hand, could look to that transcendent idea to support his vision of heaven's joys or hell's torments, of the infinite glory of God and the angels as portrayed by artists in the new Baroque style and of the machinations of the Devil and his minions.

The churches were the grandest expression of the corporate ideal, which shaped life at all levels and which can be seen in the Christian rites invariably used to enforce rules and cement fellowship. It also informed the guilds, corporations, and colleges that served the needs of craftsmen and tradesmen, inhabitants of cities, and scholars. The idea that society was composed of orders was given perhaps excessively precise form by the lawyer Charles Loyseau in his *Traité des Ordres* (1610), but it serves

to stress the significance of precedence. It was assumed that society was hierarchical and that each order had divine sanction. Wherever man found himself, at prayer or study, under arms or at work, there were collective rights and duties that had evolved as a strategy for survival. With them went the sense of belonging to a family of mutual obligations that had been a civilizing aspect of feudal society.

Surviving aspects of feudalism

Feudalism, as a set of political arrangements, was dead by 1600. But aspects of feudal society survived, notably in the countryside. Various forms of personal service were owed by peasants to landowners and, in armies and courts, assumption of office and terms of service reflected the dealings of earlier times when power lay in the ownership of land. At the highest, providing cohesion in the intermediate phase between feudal and bureaucratic regimes, the patron-client relationship contained an idea of service that was nearer to medieval allegiance than to modern contract. Liveries might be out of use, but loyalty was owed to "my lord and master": a powerful man such as Richelieu could thus describe his service to a greater patron, Louis XIII, and would expect the same from his dependents. Envisaging such a society, the reader must dismiss the idea of natural rights, which was not current until the last decades of the 18th century. Rights accrued by virtue of belonging, in two ways: first, as the subject of a prince or equivalent authority—for example, magistrates of a free town or the bishop of an ecclesiastical principality; second, as the member of a community or corporation, in which one had rights depending on the rank into which one was born or on one's craft or profession. Whatever the formula by which such rights were expressed, it would be defended with tenacity as the means of ensuring the best possible life.

Christian, corporate, feudal: each label goes only some way to defining elusive mentalities in preindustrial society. The elements of organization that they represent look artificial unless the domestic basis is taken into account. The family was the lifeblood of all associations, giving purpose and identity to people who were rarely in crowds and knew nothing like the large, impersonal organization of modern times. To stress the family is not to sentimentalize it but to provide a key to understanding a near-vanished society. The intimacies of domestic life could not anesthetize against pain and hunger: life was not softened and death was a familiar visitor. Children were especially vulnerable but enjoyed no special status. Valued as an extra pair of hands or deplored as an extra mouth to feed, the child belonged to no privileged realm of play and protection from life's responsibilities. The family might be extended by numerous relations living nearby; in Mediterranean lands it was common for grandparents or brothers and sisters, married or single, to share a house or farm. Especially in more isolated communities, inbreeding added genetic hazards to the struggle for life. Everywhere the hold of the family, and of the father over the family, strengthened by laws of property and inheritance, curtained life's narrow windows from glimpses of a freer world. It affected marriage, since land, business, and dowry were customarily of more weight than the feelings of the bride and groom. But into dowries and ceremonies long saved for would go the display required to sustain the family name. Pride of family was one aspect of the craving for office. Providing status as well as security in a hierarchical society, it was significantly weaker in the countries, notably the United Provinces and England, where trading opportunities were greatest.

Nobles and gentlemen. Between persistent poverty and the prevailing aristocratic spirit several connections can be made. The strong appeal of noble status and values was a force working generally against the pursuit of wealth and the investment that was to lead, precociously and exceptionally in Britain, to the Industrial Revolution. In France a nobleman could lose rank (*dérogeance*) by working, which inhibited him from engaging in any but a few specified enterprises. The typical relationship between landed gentleman and peasant producer was still feudal; whether represented by a range of rights and dues or by the more rigorous form of serfdom, it encouraged acceptance of the status quo in agriculture. Every state in Europe, except some Swiss cantons, recognized some form of nobility whose privileges were protected by law. Possession of land was a characteristic mark and aspiration of the elites.

The use of the two terms nobleman and gentleman indicates the difficulty of definition. The terms were loosely used to mark the essential distinction between members of an upper class and the rest. In France, above knights and esquires without distinctive title, ranged barons, viscounts, counts, and marquises, until the summit was reached with dukes and princes of the blood. In Britain, by contrast, only peers of the realm, whether entitled duke, marquess, earl, or baron, had corporate status: numbering under 200, they enjoyed few special privileges beyond membership of the House of Lords. The gentry, however, with assured social position, knighthoods, armorial bearings, and estates, were the equivalent of Continental nobles. With the nobility, they owned more than three-quarters of the land: in contrast, in France by 1789 the nobility owned barely a third. In northern and eastern Europe, where the social structure was generally simpler than in the west, nobles—*dvoriane* in Russia, *szlachta* in Poland and Hungary—were numerous. In these countries, many of those technically noble were in reality of little importance and might even, like the "barefoot *szlachta*," have no land.

Such differences apart, there were rights and privileges that most Continental nobles possessed and values to which most subscribed. The right to wear a sword, to bear a crested coat of arms, to retain a special pew in church, to enjoy such precedence on formal occasions as rank prescribed, and to have if necessary a privileged form of trial would all seem to the noble inherent and natural. As landowner he enjoyed rights over peasants, not least as judge in his own court. In France, parts of Germany, Italy, and Spain, even if he did not own the land, he could as lord still benefit from feudal dues. He could hope for special favours from his sovereign or other patron in the form of a pension or office. There were vital exemptions, as from billeting soldiers and—most valuable—from taxation. The effectiveness of governments can be measured by the extent to which they breached this principle: in France, for example, in the 18th century by the *dixième* and *vingtième* taxes, effectively on income; belatedly, in Poland, where nobles paid no tax until the chimney tax of 1775. Generally they could expect favourable treatment: special schools, privileges at university, preferment in the church, commissions in the army. They could assume that a sovereign, while encroaching on their rights, would yet share their values. Richelieu's policy exemplifies such ambivalence. A noble himself, Richelieu sought to promote the interests of his class while directing it toward royal service and clipping the wings of the over-powerful. Frederick II the Great of Prussia was not concerned about faction. Since "most commoners think meanly," he believed that nobles were best suited to serve in the government and the army. Such admiration for noble virtues did not usually extend to the political role. The decline of Continental estates and diets, with the growth of bureaucracies, largely recruited from commoners, did not mean, however, even in the west, that nobility was in retreat before the rise of the bourgeoisie. Through social preeminence, nobles maintained—and in the 18th century even tightened—their hold on the commanding heights in church and state.

Within all countries there was a distinction between higher and lower levels within the caste: in some, not only between those who were titled and the rest but, as in Spain and France, between *titulos* and grandees, a small group upon which royal blood or the achievement of some ancestor conferred privileges of a self-perpetuating kind. "The grandeeship of the counts of Lemos was made by God and time," observed the head of the family to the new Bourbon king Philip V. No less pretentious were the Condés or the Montmorencys of France. There was a tendency everywhere to the aggrandizement of estates through arranged marriage, a sovereign's favour, or the opportunities provided by war, as in Bohemia after the suppression of the revolt of 1618 or in England with the rise of the Whig families of Russell and Cavendish. In

Britain, the principle of primogeniture ensured succession to the eldest son (promoting social mobility as younger sons made their way in professions or trades). Peter I the Great of Russia legislated for the entail (1714), but without success: it was abandoned by Anna (1731) in favour of the traditional law of inheritance. However, *mayorazgo* in Castile and *fideicommissum* in parts of Italy kept vast estates together. Where the colonization of new lands was not restrained by central government, families like the Radziwiłł and Wiśniowieckis of Poland acquired huge estates. The *szlachta* of Hungary also cherished privileges as descendants of warriors and liberators. There, Prince Miklós Esterházy, patron of a private orchestra and of Joseph Haydn, excelled all by the end of the 17th century with his annual revenue of 700,000 florins. In Russia, where wealth was measured in serfs, Prince Cherkanski was reckoned in 1690 to have 9,000 peasant households.

Status increasingly signified economic circumstances. In France, where subtle nuances escaped the outsider, one trend is revealing. The old distinction between "sword" and "gown" lost much importance. Age of title came to mean more for antiquarians and purists than for men of fashion who would not scorn a mésalliance if it "manured the land." Most daughters of 18th-century tax farmers married the sons of nobles. The class was open to new creations, usually through purchase of an office conferring nobility. When, in a regulation of 1760, the year 1400 was made a test of antiquity, fewer than 1,000 families were eligible. The tendency was toward the formation of a plutocracy. Nobles came to dominate the church and the army, even to penetrate government, from which it had been the policy of the early Bourbons to exclude them. The noble order numbered about 120,000 families by 1789. By then the nobles, particularly those of the country who seldom came to court, had brought their rearguard action to a climax to preserve their privileges—for example, by Ségur's ordinance of 1781, reserving army commissions to nobles of at least four generations. This "feudal reaction" contributed to the problems of government in the years before the Revolution. In Russia, at the height of the conservative reaction that had already secured the abolition (1762) of the service obligation imposed by Peter I, Catherine II the Great was forced to abandon liberal reforms. The Pugachov rising (1773–74) alerted landowners to the dangers of serfdom, but it was reckoned that three-fifths of all landowners owned fewer than 20 serfs. The census of 1687 showed that there were half a million nobles in Spain. But *hidalguia* might mean little more than a Spaniard's estimation of himself. Without a substantial *señorio* (estate), the hidalgo was insignificant.

When "living nobly" meant not working and hidalgos or *szlachta* attached themselves to a great house for a coat and a loaf, faction became more dangerous and aristocratic interests more resistant to change. It took courage for a sovereign to tackle the entrenched power of nobility in diets, as did the Habsburg queen Maria Theresa (1740–80) in her Austrian and Bohemian lands. Nowhere in Europe did nobles take themselves more seriously, but they were the readier to accept curtailment of their political rights because they enjoyed a healthy economic position. Vienna's cosmopolitan culture and Baroque palaces were evidence of not only the success of the regime in drawing nobles to the capital but also the rise in manorial rents. Nobles played a decorative role in the most ceremonious court in 18th-century Europe. Charles VI (1711–40) had provided 40,000 posts for noble clients. Maria Theresa, concerned about expense, reduced the number of chamberlains to 1,500. It was left to her son Joseph II to attack noble privileges at every point, right up to the abolition of serfdom. There was a correlation between the advance of government and the curtailment of noble privilege. Inevitably it was an uneven process, depending much on the resolution of a ruler. In Sweden it was to the poor gentlemen, a high proportion of its 10,000 nobles, that Charles XI had appealed in his successful promotion of absolutist reforms in the 1680s. After 1718 the same conservative force militated against royal government. The aristocratic reaction of the age of liberty saw the reassertion of the traditional principle that the nobility were the guardians of the country's liberties. So the Swedish upper class arrived at the position of their British counterparts and obtained that power, not divorced from responsibility, which was envied and extolled by the philosophes who regretted its absence from France and sought consolation in the works of Montesquieu. A central idea of his *L'Esprit des lois* (1748; *The Spirit of Laws*) was that noble privilege was the surest guarantee of the laws against despotism. That could not be said of Prussia, although a Junker's privilege was wedded to a subject's duty. In exchange for the loss of political rights, Junkers had been confirmed in their social and fiscal privileges: with the full rigour of serfdom (*Leibeigenschaft*) and rights of jurisdiction over tenants went a secure hold over local government. Under the pressure of war and following his own taste for aristocratic manners, Frederick II taught them to regard the army or civil service as a career. But Frederick disappointed the philosophes who expected him to protect the peasantry. The nobles meanwhile acquired a pride in militarism that was to be potent in the creation of the 19th-century German state. The class became more numerous but remained relatively poor: Junkers often had to sell land to supplement meagre pay. Frederick's working nobility sealed the achievements of his capable predecessors. The price paid indicates the difficulties inherent in any attempt to reconcile the interests of the dominant class to the needs of society.

Nobility also had a civilizing role. Europe would be immeasurably poorer without the music, literature, and architecture of the age of aristocracy. The virtues of classical taste were to some extent those of aristocracy: splendour restrained by formal rules and love of beauty uninhibited by utilitarian considerations. There was much that was absurd in the pretensions of some patrons; illusions of grandeur are rarely the best basis for the conceiving of great art. The importance of bourgeois patronage should not be overlooked, otherwise no account would be taken of Holland's golden age. Where taste was unaffected by the need for display (as could not be said of Louis XIV's Versailles) or where a wise patron put his trust in the reputedly best architect, art could triumph. Civilizing trends were prominent, as in England, where there was a free intellectual life. New money, as lavished by the Duke of Chandos, builder of the great house of Canons and patron of the composer George Frideric Handel, could be fruitful. Also important was the fusion of aristocratic style with ecclesiastical patronage, as could occur where noblemen enjoyed the best preferment and abbots lived like nobles: the glories of the German Baroque at Melk, Ottobeuren, and Vierzehnheiligen speak as much of aristocracy as of the Christian Gospel.

In contrast with Sweden, where, in the 18th century, talent was recognized and the scientists Carolus Linnaeus and Emanuel Swedenborg were ennobled, or France, where the plutocracy encountered the Enlightenment without discomfort, the most sterile ground for aristocratic culture was to be found where there was an enforced isolation, as in Spain or Europe's poor marches and remotest western shores. Visitors to Spain were startled by the ignorance of the men and the passivity of the women. Life in Poland, Hungary, and Ireland resolved itself for many of the gentry into a simple round of hunting and carousing. The urban aspect of noble culture needs stress, which is not surprising when its classical inspiration is recalled. Even in England, where educated men favoured country life and did not despise the country town, society would have been poorer without the intense activity of London. All the greater was the importance of the capital cities—Warsaw, St. Petersburg, Budapest, and Dublin—in countries that might not otherwise have generated fine art or architecture.

The aristocratic spirit transcended frontiers. For the nobleman Europe was the homeland. Italian plasterers and painters, German musicians, and French cabinetmakers traveled for high commissions. There were variations reflecting local traditions: the Baroque style was interpreted distinctively in Austria, Italy, Spain, and France. But high style reveals certain underlying principles and convictions. The same is true of the intellectual life of Europe, reflecting as it did two main sources, French and English. It

was especially to France that the two most powerful rulers of eastern Europe, Frederick II and Catherine II, looked for mentors in thought and style. The French language, deliberately purified from the time of Richelieu and the foundation of the Academy, was well adapted to the clear expression of ideas. The salons stimulated the discussion of ideas and engendered a distinctive style. Feminine insights there contributed to a rational culture that was also responsive to the claims of sensibility.

The bourgeoisie. The European bourgeoisie presents faces so different that common traits can be discerned only at the simplest level: the possession of property with the desire and means to increase it, emancipation from past precepts about investment, a readiness to work for a living, and a sense of being superior to town workers or peasants. With their social values—sobriety, discretion, and economy—went a tendency to imitate the style of their social superiors. In France the expectations of the bourgeoisie were roused by education and relative affluence to the point at which they could be a revolutionary force once the breakdown of royal government and its recourse to a representative assembly had given them the voice they had lacked. Everywhere the Enlightenment was creating a tendency to be critical of established institutions (notably, in Roman Catholic countries, the church), together with a hunger for knowledge as a tool of progress.

Such dynamic characteristics, conducive to social mobility, should not obscure the essential feature of bourgeois life: conservativism within a corporate frame. In 1600 a town of more than 100,000 would have been thought enormous: only London, Paris, Naples, Seville, Venice, Rome, and Constantinople came into that class. Half in Asia but enmeshed in the European economic system, Constantinople was unique: it was a megalopolis, a gigantic consumer of the produce of subject lands. London's growth was more significant for the future: it was a seaport and capital, but with a solid base in manufacturing, trade, and finance. Like Naples, it was a magnet for the unemployed and restless. In 1700 there were only 48 towns in Europe with a population of more than 40,000; all were regarded as important places. Even a smaller city might have influence in the country, offering a range of services and amenities; such was Amiens, with 30,000 inhabitants and 36 guilds, including bleachers, dyers, and finishers of the cloth that was woven in nearby villages but sent far afield. Most towns had fewer than 10,000 inhabitants, and a fair number only about 1,000; most towns remained static or declined. Some grew, however: between 1600 and 1750 the proportion of the population living in towns of more than 20,000 doubled from 4 to 8 percent, representing about half the total urban population.

A universal phenomenon was the growth of capital cities, which benefited from the expansion of government, particularly if, as was usual, the court was within the city. Growth could acquire its own momentum, irrespective of the condition of the country: besides clients and servants of all kinds, artisans, shopkeepers, and other providers of services swelled the ranks. Warsaw's size doubled during Poland's century of distress to stand at 120,000 by 1772. St. Petersburg, in 1700 a swamp, acquired 218,000 inhabitants by 1800. Berlin, the simple electoral capital of some 6,000 inhabitants in 1648, rose with the success of the Hohenzollerns to a population of 150,000 by 1786. By then the population of Vienna—home of the imperial court, a growing professional class, a renowned university and other schools, and hospitals—had reached 220,000. The population of Turin, capital of relatively small Savoy, also doubled in the 18th century. Rome did not suffer too obviously from the retreat of the popes from a leading political role, but the Holy City (140,000 inhabitants in 1700) was top-heavy, with little in the way of manufacturing. All these cities owed their growth to their strategic place in the government rather than to their economic importance.

Other cities grew around specialized industries or from opportunities for a wider trade than was possible where markets were limited by the range of horse and mule. Growth was likely to be slow where, as in Lyon, Rouen, and Dresden, production continued to be along traditional lines or, in ports such as Danzig, Königsberg, or Hamburg, where trading patterns remained essentially the same. Enterprise, by contrast, brought remarkable growth in Britain, where Manchester and Birmingham both moved up from modest beginnings to the 100,000-population mark during the 18th century. Atlantic ports thrived during the same period with the increase in colonial trade: into this category fall Bordeaux, Nantes, Bristol, Liverpool, and Glasgow. Marseille recovered quickly from the plague of 1720 and grew on the grain import trade; more typical of Mediterranean cities were stagnant Genoa, Venice, and Palermo, where Austrian policy in the 18th century, favouring Milan, was an adverse factor.

A typical urban experience, where there was no special factor at work, was therefore one of stability. The burgher of 1600 would have felt at home in the town of his descendant five generations later. There might have been calamities along the way: at worst, siege or assault, plague, a particularly serious recession, or a fire, such as destroyed Rennes in 1720. Some building or refacing of houses would have occurred, mainly within the walls. In more fortunate cities, where there was continuing economic stability or strong corporate identity—as in the siege victims La Rochelle (1628) or Magdeburg (1631)—recovery even from the worst of war experiences could be rapid. The professions, notably the church and law, were tough, having large interests in the town and in the property in and around it. Guild discipline, inhibiting in fair years, was a strength in foul ones. Not all towns were so resilient, however. Some Polish towns never recovered from the effects of the Great Northern War; others throughout northern and eastern Europe were victims of the rise of the self-sufficient estate, which supplied needs such as brewing that the town had previously offered. Some Italian and Spanish towns, such as Cremona, Toledo, and Burgos, were affected by the decline of manufacturing and the shift of trade to the Atlantic economies.

It was possible for a town that had a special importance in the sphere of church or law (Angers, Salzburg, or Trier, for example) to enjoy a quiet prosperity, but there was a special kind of deadness about towns that had no other raison d'être than to be host to numerous clergy. Valladolid contained 53 religious houses "made up principally of consumers" according to a report of 1683. Most numerous were the quiet places that had never grown from their basic function of providing a market. England's archaic electoral system provided graphic evidence of such decay, leaving its residue of "rotten boroughs."

Between these extremes lay the mass of towns of middling size, each supervised by a mayor and corporation, dignified by one large church and probably several others serving ward or parish (and, if Catholic, by a religious house of some kind), and including a law court, guildhall, school, and, of course, market. With its bourgeois crust of clerics, lawyers, officials, merchants, and shopkeepers and master craftsmen catering for special needs—fine fabrics, clothing, hats, wigs, gloves, eyeglasses, engravings if not paintings, china, silver, glassware, locks, and clocks—the city was a world apart from the peasant. The contrast was emphasized by the walls, the gates that closed at night, the cobbles or setts of the roads, the different speech and intonation, the well-fed look of some citizens, and above all the fine houses, suggesting as much an ordered way of life as the wealth that supported it. The differences were blurred, however, by the pursuits of the urban landowners; by ubiquitous animals, whether bound for market or belonging to the citizens; by the familiar poverty and filth of the streets and the reek of the tannery and the shambles.

It is easier to recreate the physical frame than the mentalities of townspeople. Letters, journals, government reports and statistics, wills, and contracts reveal salient features. The preference for safe kinds of investment could be exploited by governments for revenue, as notably by the French: in 1661 Colbert found that, of 46,000 offices of justice and finance, 40,000 were unnecessary. There was an inclination to buy land for status and security. Around cities like Dijon, most of the surrounding land was owned by the bourgeois or the recently ennobled. Custom and ceremony were informed by a keen sense of hierarchy, as

in minutely ordered processions. The instinct to regulate was stiffened by the need to restrain servants and journeymen and to ensure that apprentices waited for the reward of their training. Religion maintained its hold more firmly in the smaller towns, while the law was respected as the mainstay of social order and the road to office in courts or administration even where, as in Italy, it was palpably corruptible. There were certain communal dreads, military requisitioning and billeting high among them. There was generally a resolve to ward off beggars, to maintain grain stores, to close the gates to the famished when crops failed, and to enforce quarantine.

Within towns, popular forms of government were abandoned as power was monopolized by groups of wealthy men. This process can be studied in the Dutch towns in the years after 1648 when regents gained control. Everywhere elites were composed of those who had no business role. Among other labels for this period, when a profession seemed to be more desirable than trade, "a time of lawyers" might be appropriate. Trained to contend, responsive to new ideas, at least dipping into the waters of the Enlightenment, those lawyers who were cheated, by sheer numbers, of the opportunity to rise might become a dissident element, especially in countries where political avenues were blocked and the economy was growing too slowly to sustain them. Sometimes the state moved in to control municipal affairs, as in France where intendants were given wide powers toward the end of Louis XIV's reign. In Spain, towns came into the hands of local magnates.

A more serious threat to the old urban regime lay in another area where discontents bred radicalism: the guilds. Not until the French Revolution and the radical actions of Joseph II of Austria were guilds anywhere abolished. They had long displayed a tendency to oligarchic control by hereditary masters. They became more restrictive in the face of competition and growing numbers of would-be members and so drove industries, particularly those suited to dispersed production, back to the countryside. For this reason, such cities as Leiden, Rouen, Cologne, and Nürnberg actually lost population in the 18th century. To compensate for falling production, masters tended to put pressure on the relatively unskilled level, where there were always more workers than work. Journeymen's associations sought to improve their situation, sometimes through strikes. The building trade was notorious for its secret societies. The decline of the guilds was only one symptom of the rise in population. Another was the rise in urban poverty, as pressure on resources led to price increases that outstripped wages. In late 18th-century Berlin, which was solidly based on bureaucracy, garrison, and numerous crafts, a third of the population still lacked regular work. The plight of the poor was emphasized by the affluence of increasing numbers of fellow citizens. However class conflict is interpreted, it is clear that its basic elements were by that time present and active.

The peasantry. In 1700 only 15 percent of Europe's population lived in towns, but that figure concealed wide variations: at the two extremes by 1800 were Britain with 40 percent and Russia with 4 percent. Most Europeans were peasants, dependent on agriculture. The majority of them lived in nucleated settlements and within recognized boundaries, those of parish or manor, but some, in the way characteristic of the hill farmer, lived in single farms or hamlets. The type of settlement reflected its origins: pioneers who had cleared forests or drained swamps, Germans who had pressed eastward into Slav lands, Russians who had replaced conquered Mongols, Spaniards who had expelled the Moors. Each brought distinctive characteristics. Discounting the nomad fringe, there remains a fundamental difference between serfs and those who had more freedom, whether as owners or tenants paying some form of rent but both liable to seigneurial dues. There were about one million serfs in eastern France and some free peasants in Russia, so the pattern is untidy; but broadly it represents the difference between eastern and western Europe.

The Russian was less attached to a particular site than his western counterparts living in more densely populated countries and had to be held down by a government determined to secure taxes and soldiers. The imposition of serfdom was outlined in the Ulozhenie, the legal code of 1649, which included *barschina* (forced labour). One consequence was the decline of the mir, the village community, with its fellowship and practical services; another was the tightening of the ties of mutual interest that bound tsar and landowner. Poles, Germans (mainly those of the east and north), Bohemians, and Hungarians were subject to a serfdom less extreme only in that they were treated as part of the estate and could not be sold separately; the Russian serf, who could, was more akin to a slave. Russian state peasants, an increasingly numerous class in the 18th century, were not necessarily secure; they were sent out to farm new lands. Catherine the Great transferred 800,000 serfs to private ownership. The serf could not marry, move, or take up a trade without his lord's leave. He owed labour (*robot*) in the Habsburg lands for at least three days a week and dues that could amount to 20 percent of his produce. The Thirty Years' War hastened the process of subjection, already fed by the west's demand for grain; peasants returning to ruined homesteads found that their rights had vanished. The process was resisted by some rulers, notably those of Saxony and Brunswick: independent peasants were a source of revenue. Denmark saw an increase in German-style serfdom in the 18th century, but most Swedish peasants were free—their enemies were climate and hunger, rather than the landowner. Uniquely, they had representation in their own Estate in the Riksdag.

Through much of Germany, France, Italy, Spain, and Portugal there was some form of rent or sharecropping. Feudalism survived in varying degrees of rigour, with an array of dues and services representing seigneurial rights. It was a regime that about half of Europe's inhabitants had known since the Middle Ages. In England all but a few insignificant forms had gone, though feudal spirit lingered in deference to the squire. Enclosures were reducing the yeoman to the condition of a tenant farmer or, for most, a dependent, landless labourer. Although allodial tenures (absolute ownership) ensured freedom from dues in some southern provinces, France provides the best model for understanding the relationship of lord and peasant. The seigneur was generally, but not invariably, noble: a seigneury could be bought by a commoner. It had two parts. The *domaine* was the house with its grounds: there were usually a church and a mill, but not necessarily fields and woods, for those might have been sold. The *censives,* lands subject to the seigneur, still owed dues even if no longer owned by him. The *cens,* paid annually, was significant because it represented the obligations of the peasant: free to buy and sell land, he still endured burdens that varied from the trivial or merely vexatious to those detrimental to good husbandry. They were likely to include *banalités,* monopoly rights over the mill, wine press, or oven; *saisine* and *lods et ventes,* respectively a levy on the assets of a *censitaire* on death and a purchase tax on property sold; *champart,* a seigneurial tithe, payable in kind; monopolies of hunting, shooting, river use, and pigeon rearing; the privilege of the first harvest, for example, *droit de banvin,* by which the seigneur could gather his grapes and sell his wine first; and the corvées, obligatory labour services. Seigneurial rule had benevolent aspects, and justice in the seigneurial court could be even-handed; seigneurs could be protectors of the community against the state's taxes and troops. But the regime was damaging, as much to the practice of farming as to the life of the peasants, who were harassed and schooled in resistance and concealment. To identify an 18th-century feudal reaction—as some historians have called the tendency to apply business principles to the management of dues—is not to obscure the fact that for many seigneurs the system was becoming unprofitable. By 1789 in most provinces there was little hesitation: the National Assembly abolished feudal dues by decree at one sitting because the peasants had already taken the law into their own hands. Some rights were won back, but there could be no wholesale restoration.

Besides priest or minister, the principal authority in most

peasants' lives was that of the lord. The collective will of the community also counted for much, as in arrangements for plowing, sowing, and reaping, and even in some places the allocation of land. The range of the peasant's world was that of a day's travel on foot or, more likely, by donkey, mule, or pony. He would have little sense of a community larger than he could see or visit. His struggle against nature or the demands of his superiors was waged in countless little pockets. When peasants came together in insurgent bands, as in Valencia in 1693, there was likely to be some agitation or leadership from outside the peasant community—in that case from José Navarro, a surgeon. There needed to be some exceptional provocation, like the new tax that roused Brittany in 1675. After the revolt had been suppressed, the *parlement* of Rennes was exiled to a smaller town for 14 years: clearly government understood the danger of bourgeois complicity. Rumour was always potent, especially when tinged with fantasy, as in Stenka Razin's rising in southern Russia, which evolved between 1667 and 1671 from banditry into a vast protest against serfdom. Generally, cooperation between villages was less common than feuding, the product of centuries of uneasy proximity and conflict over disputed lands.

The peasant's life was conditioned by mundane factors: soil, water supplies, communications, and above all the site itself in relation to river, sea, frontier, or strategic route. The community could be virtually self-sufficient. Its environment was formed by what could be bred, fed, sown, gathered, and worked within the bounds of the parish. Fields and beasts provided food and clothing; wood came from the fringe of wasteland. Except in districts where stone was available and easy to work, houses were usually made of wood or a cob of clay and straw. Intended to provide shelter from the elements, they can be envisaged as a refinement of the barn, with certain amenities for their human occupants: hearth, table, and benches with mats and rushes strewn on a floor of beaten earth or rough stone. Generally there would be a single story, with a raised space for beds and an attic for grain. For his own warmth and their security the peasant slept close to his animals, under the same roof. Cooking required an iron pot, sometimes the only utensil named in peasant inventories. Meals were eaten off wood or earthenware. Fuel was normally wood, which was becoming scarce in some intensively cultivated parts of northern Europe, particularly Holland, where much of the land was reclaimed from sea or marsh. Peat and dried dung also were used, but rarely coal. Corn was ground at the village mill, a place of potential conflict: only one man had the necessary expertise, and his clients were poorly placed to bargain. Women and girls spun and wove for the itinerant merchants who supplied the wool or simply for the household, for breeches, shirts, tunics, smocks, and gowns. Clothes served elemental needs: they were usually thick for protection against damp and cold and loose-fitting for ease of movement. Shoes were likely to be wooden clogs, as leather was needed for harnesses. Farm implements—plows (except for the share), carts, harrows, and many of the craftsman's tools—were made of wood, seasoned, split or rough-hewn. Few possessed saws; in Russia they were unknown before 1700. Iron was little used and was likely to be of poor quality. Though it might be less true of eastern Europe where, as in Bohemia, villages tended to be smaller, the community would usually have craftsmen—a smith or a carpenter, for example—to satisfy most needs. More intricate skills were provided by traveling tinkers.

The isolated villager might hear of the outside world from such men. Those living around the main routes would fare better and gather news, at least indirectly, from merchants, students, pilgrims, and government officials or, less reputably, from beggars, gypsies, or deserters (a numerous class in most states). He might buy broadsheets, almanacs, and romances, produced by enterprising printers at centres such as Troyes, to be hawked around wherever there were a few who could read. So were kept alive what became a later generation's fairy tales, along with the magic and astrology that they were not reluctant to believe. Inn and church provided the setting for business, gossip, and rumour. Official reports and requirements were posted and village affairs were conducted in the church. The innkeeper might benefit from the cash of wayfarers but like others who provided a service, he relied chiefly on the produce of his own land. Thus the rural economy consisted of innumerable self-sufficient units incapable of generating adequate demand for the development of large-scale manufactures. Each cluster of communities was isolated within its own market economy, proud, and suspicious of outsiders. Even where circumstances fostered liberty, peasants were pitifully inadequate in finding original solutions to age-old problems but were well-versed in strategies of survival, for they could draw on stores of empirical wisdom. They feared change just as they feared the night for its unknown terrors. Their customs and attitudes were those of people who lived on the brink: more babies might be born but there would be no increase in the food supply.

In the subsistence economy there was much payment and exchange in kind; money was hoarded for the occasional purchase, to the frustration of tax collectors and the detriment of economic growth. Demand was limited by the slow or nonexistent improvement in methods of farming. There was no lack of variety in the agricultural landscape. Between the temporary cultivation of parts of Russia and Scandinavia, where slash-and-burn was encouraged by the extent of forest land, and the rotation of cereal and fodder crops of Flanders and eastern England, 11 different methods of tillage have been identified. Most common was some version of the three-course rotation that Arthur Young denounced when he traveled in France in 1788. He observed the subdivision and wide dispersal of holdings that provided a further obstacle to the diversification of crops and selective breeding. The loss of land by enclosure pauperized many English labourers. But the development in lowland England of the enclosed, compact economic unit—the central feature of the agrarian revolution—enabled large landowners to prosper and invest and small farmers to survive. They were not trapped, like many Continental peasants, between the need to cultivate more land and the declining yields of their crops, which followed from the loss of pasture and of fertilizing manure. Without capital accumulation and with persisting low demand for goods, economic growth was inhibited. The work force was therefore tied to agriculture in numbers that depressed wage rates, discouraged innovation, and tempted landowners to compensate by some form of exploitation of labour, rights, and dues. Eighteenth-century reformers condemned serfdom and other forms of feudalism, but they were as much the consequence as the cause of the agricultural malaise.

THE ECONOMIC ENVIRONMENT

Innovation and development. Every country had challenges to overcome before its resources could be developed. The possession of a coastline with safe harbours or of a navigable river was an important asset and, as by Brandenburg and Russia, keenly fought for; so were large mineral deposits, forests, and fertile soil. But communications were primitive and transport slow and costly even in favoured lands. Napoleon moved at the same speed as Julius Caesar. By horse, coach, or ship, it was reckoned that 24 hours was necessary to travel 60 miles. In one area, however, innovation had proceeded at such a pace as to justify terms such as "intellectual" or "scientific" revolution; yet there remained a yawning gap between developments in theoretical science and technology. In the age of Newton the frontiers of science were shifting fast, and there was widespread interest in experiment and demonstration, but one effect was to complete the separation of a distinctive intellectual elite: the more advanced the ideas, the more difficult their transmission and application. There was a movement of thought rather than a scientific movement, a culture of inquiry rather than of enterprise. Only in the long term was the one to lead to the other, through the growing belief that material progress was possible. Meanwhile, advances were piecemeal, usually the work of individuals, often having no connection with business. Missing was not only that association of interests that characterizes industrial society but also the educational ground: schools and universities were wedded

to traditional courses. Typical inventors of the early industrial age were untutored craftsmen, such as Richard Arkwright, James Watt, or John Wilkinson. Between advances in technology there could be long delays.

As those names suggest, Britain was the country that experienced the breakthrough to higher levels of production. The description "Industrial Revolution" is misleading if applied to the economy as a whole, but innovations in techniques and organization led to such growth in iron, woolens, and, above all, cotton textiles in the second half of the 18th century that Britain established a significant lead. It was sustained by massive investment and by the wars following the French Revolution, which shut the Continent off from developments that in Britain were stimulated by war. Factors involved in the unique experience of a country that contained only 1 in 20 of Europe's inhabitants expose certain contrasting features of the European economy. The accumulation of capital had been assisted by agricultural improvement, the acquisition of colonies, the operation of chartered companies (notably the East India Company), trade-oriented policies of governments (notably that of William Pitt during the Seven Years' War), and the development of colonial markets. There existed a relatively advanced financial system, based on the successful Bank of England (founded 1694), and interest rates were consistently lower than those of European rivals. This was particularly important in the financing of road and canal building, where large private investment was needed before profit was realized. Further advantages included plentiful coal and iron ore and swift-flowing streams in the hilly northwest where the moist climate was suited to cotton spinning. The labour force was supplemented by Irish immigrants. A society that cherished political and legal institutions characteristic of the ancien régime also exhibited a free and tolerant spirit, tending to value fortune as much as birth. Comparison with Britain's chief rival in the successive wars of 1740–48, 1756–63, and 1778–83 is strengthened by the consequences of those wars: for France the slide toward bankruptcy, for Britain a larger debt that could still be funded without difficulty.

Yet the French enjoyed an eightfold growth in colonial trade between 1714 and 1789, considerably larger than that of the British. The Dutch still had the financial strength, colonies, trading connections, and at least some of the entrepreneurial spirit that had characterized them in the 17th century. Enlightened statesmen such as the Marquês de Pombal in Portugal, Charles III of Spain, and Joseph II of Austria backed measures designed to promote agriculture and manufacturing. The question of why other countries lagged behind Britain leads to consideration of material and physical conditions, collective attitudes, and government policies. It should not distort the picture of Europe as a whole or obscure the changes that affected the demand for goods and the ability of manufacturers and traders to respond.

The mercantilist theory—which still appealed to a statesman like Frederick the Great, as it had to his great-grandfather—was grounded on the assumption that markets were limited: to increase trade, new markets had to be found. Mobility within society and increased spending by commonfolk, who were not expected to live luxuriously, were treated as symptoms of disorder. Mercantilists were concerned lest the state be stripped of its treasure and proper distinctions of status be undermined. The moral context is important: mercantilism belongs to the world of the city-state, the guilds, and the church; its ethical teaching is anchored in the medieval situation. By 1600 the doctrine that usury was sinful was already weakened beyond recovery by evasion and example. Needy princes borrowed, but prejudice against banks lingered, reinforced by periodic demonstrations of their fallibility, as in the failure of John Law's Banque Générale in Paris in 1720. Productive activity was not necessarily assumed to be a good thing. Yet it is possible, throughout the period, to identify dynamic features characteristic of capitalism in its developed, industrial phase.

Early capitalism. Two broad trends can be discerned. The shift from the Mediterranean and its hinterlands to the Atlantic seaboard continued, although there was still vigorous entrepreneurial activity in certain Mediterranean regions; Venice stood still, but Marseille and Barcelona prospered. More striking was the growing gap between the economic systems of the east, where capital remained largely locked up in the large estates, and the west, where conditions were more favourable to enterprise. With more widespread adoption of utilitarian criteria for management went a sterner view of the obligation of workers. Respect for the clock, with regular hours and the reduction of holidays for saints' days (already achieved in Protestant countries), was preparing the way psychologically for the discipline of the factory and mill. Handsome streets and squares of merchants' houses witnessed to the prosperity of Atlantic ports such as Bordeaux, Nantes, and Bristol, which benefited from the reorientation of trade. Above all, Amsterdam and London reflected the mutually beneficial activity of trade and services. From shipbuilding, so demanding in skills and raw materials, a network of suppliers reached back to forests, fields, and forges, where timber, iron, canvas, and rope were first worked. Chandlering, insurance, brokerage, and credit-trading facilitated international dealing and amassing of capital. Fairs had long counteracted the isolation of regional economies: Lyon on the Rhône, Hamburg on the Elbe, and Danzig on the Vistula had become centres of exchange, where sales were facilitated by price lists, auctions, and specialization in certain commodities. Retailing acquired a modern look with shops catering to those who could afford coffee from Brazil or tobacco from Virginia; unlike earlier retailing, the goods offered for sale were not the products of work carried out on the premises. The dissemination of news was another strand in the pattern. By 1753 the sale of newspapers exceeded seven million: the emphasis was on news, not opinion, and price lists were carried with the news that affected them. Seamen were assisted by the dredging of harbours and improved docks and by more accurate navigational instruments and charts. In 1600 there were 18 lighthouses on or off the shores of Europe; in 1750 there were 82. The state also improved roads and made them safe for travelers; by 1789 France had 7,500 miles of fine roads, built largely by forced labour. By 1660 nearly every Dutch city was linked by canals. Following their example, Elector Frederick William in Brandenburg and Peter the Great in Russia linked rivers to facilitate trade. In France Colbert's plan for the Languedoc canal (completed 1682) involved private as well as state capital. England's canal builders, notably the Duke of Bridgewater, had to find their own resources: consequently, capital was applied to the best effect to serve mines and factories. The general survival of tolls and the resistance of interested parties to their removal imposed constraints on most governments. The abolition of internal customs was therefore a priority for enlightened reformers such as Anne-Robert-Jacques Turgot in France and Joseph II in Austria. Germany's many princes had taken advantage of weak imperial authority to impose the tolls, which produced revenue at the cost of long-distance trade. Numerous external tariffs remained an obstacle to the growth of trade. Radical action, however, could be dangerous. Turgot's attempt to liberate the grain trade in France led to shortages, price rises, and his own downfall. The free trade treaty of 1786 of the French foreign minister, the Count de Vergennes, also had unfortunate consequences: France was flooded by cheap English textiles, peasant weavers were distressed, and the ground was prepared for the popular risings of 1789.

One important development was the adoption in western Europe of the existing Italian practice of using bills of exchange as negotiable instruments; it was legalized in Holland in 1651 and in England in 1704. Bankers who bought bills, at a discount to cover risk, thereby released credit that would otherwise have been immobilized. The other aspect of the financial revolution was the growth of banking facilities. In 1660 there had been little advance in a century, since princes and magnates, after raising money too easily, had reneged on debts and damaged the fragile system. Great houses, such as the Fuggers, had been ruined. The high interest rates demanded by survivors contributed to the recession of the 17th century. There were some municipal institutions, such as the Bank of Ham-

burg and the great Bank of Amsterdam, which played a crucial part in Dutch economic growth by bringing order to the currency and facilitating transfers. They provided the model for the Bank of England, which was founded in 1694 as a private company and was soon to have a relationship of mutual dependence with the state. The first state bank was that founded in Sweden in 1656; to provide a substitute for Sweden's copper currency, it issued the first bank notes. Overproduced and not properly secured, they soon lost value. Law's ambitious scheme for a royal bank in France foundered in 1720 because it was linked to his Louisiana company and its inflated prospects. After its failure tax farmers resumed their hold over state finance, and as a result interest rates remained higher than those of Britain because there was no secure central agency of investment. Law's opponents were shortsighted: in Britain, where a central bank was successful, a large expansion of private banking also took place.

Meanwhile silver, everywhere the basic unit of value, remained in short supply. One-sided trade with the east meant a continuous drain. Insufficient silver was mined; declining imports from the New World did not affect only Spain. Governments tried to prevent the clipping of coins and so revalued. The deficiency remained, providing evidence for mercantilist policies. Negotiable paper in one form or other went some way to meet the shortage of specie. Stock exchanges, commercial in their original function, dealt increasingly in government stocks. Joint-stock companies became a common device for attracting money and spreading risk. By the mid-18th century the operations of commerce, manufacturing, and public finance were linked in one general system; a military defeat or economic setback affecting credit in one area might undermine confidence throughout the entire investing community.

The old industrial order. Operations of high finance represented the future of capitalist Europe. The economy as a whole was still closer in most respects to the Middle Ages. Midland and northern England, a belt along the Urals, Catalonia, the Po valley, and Flanders were scenes of exceptionally large-scale operations during the 18th century. The mines, quarries, mills, and factories of entrepreneurs such as Josse van Robais, the Dutch industrialist brought in by Colbert to produce textiles in Abbeville, only emphasized, by contrast, the primitive conditions of most manufacturing enterprise. Technology relied on limited equipment. Peter the Great saw it at its most impressive when he visited Holland in 1697. In villages along the Zaan River were lumber saws powered by 500 windmills and yards equipped with cranes and stacked with timber cut to set lengths to build *fluitschips* to a standard design.

The typical unit of production, however, was the domestic enterprise, with apprentices and journeymen living with family and servants. The merchant played a vital part in the provision of capital. When metalworkers made knives or needles for a local market, they could remain their own masters. For a larger market, they had to rely on businessmen for fuel, ore, wages, and transport. In textiles the capital and marketing skills of the entrepreneur were essential to cottagers. This putting-out system spread as merchants saw the advantages of evading guild control. When the cotton industry was developed around Rouen and Barcelona, it was organized in the same way as woolen textiles. In the old industrial order, output could be increased only in proportion to the number of workers involved. In England the new order was evolving, and ranks of machines in barracklike mills were producing for a mass market. The need to produce economically could transform an industry, as in Brabant, where peasants moved into the weaving side of the linen trade and then established bleaching works that ruined traditionally dominant Haarlem. It also altered the social balance, as in electoral Saxony where, between 1550 and 1750, the proportion of peasants who made most of their living by industry rose from 5 to 30 percent of the population. With such change came the dependence on capital and the market that was to make the worker so vulnerable.

Inevitably the expansion of domestic manufactures brought problems of control, which were eventually resolved by concentration in factories and by technical advances large enough to justify investment in machinery. Starting with the Lombe brothers' silk mills, their exploitation of secrets acquired from Italy (1733), and John Kaye's flying shuttle, British inventions set textile production on a dizzy path of growth. Abraham Darby's process of coke smelting was perhaps the most important single improvement, since it liberated the iron founder from dependence on charcoal. The shortage of timber, a source of anxiety everywhere except in Russia and Scandinavia, proved to be a stimulus to invention and progress. Technical development on the Continent was less remarkable. The nine volumes of the *Theatrum Machinarum* (1724), Jakob Leupold's description of engineering, records steady development reflecting the craftsman's empirical outlook. Improvement could be modest indeed. A miller could grind 37 pounds (17 kilograms) of flour each day in the 12th century; by 1700 it might have been 55 pounds. In some areas there were long intervals between theoretical advances and technological application. Galileo, Evangelista Torricelli, Otto von Guericke, and Blaise Pascal worked on the vacuum in the first half of the 17th century, and Denis Papin later experimented with steam engines; however, it was not until 1711 that Thomas Newcomen produced a model that was of any practical use despite the great need for power. Mining, already well advanced, was held back by difficulties of drainage. In the Rohrerbuhel copper mines in the Tyrol, the Heiliger Geist shaft, at 2,900 feet (886 metres), remained the deepest in the world until 1872; a third of its labour force was employed in draining. Increases in productivity were generally found in those manufacturing activities where, as in the part-time production of linen in Silesia, the skills required were modest and the raw material could be produced locally.

Specialized manufacturing, evolving to meet the rising demand generated by the enrichment of the upper classes, showed significant growth. Wherever technical ingenuity was challenged by the needs of the market, results could be impressive. Printing was of seminal importance, since the advance of knowledge depended on it. Improvements in type molds and founding contributed to a threefold increase between 1600 and 1700 in the number of pages printed in a day. The Hollander, a pulverizing machine (*c.* 1670), could produce more pulp for paper than eight stamping mills. The connection between technical innovation and style is illustrated by improvements in glass-making that made possible not only the casting of large sheets for mirrors but also, by 1700, the larger panes required for the sash windows that were replacing the leaded panes of casements. Venice lost its dominant position in the manufacture of glass as rulers set up works to save expensive imports. A new product sometimes followed a single discovery, as when the Saxons Ehrenfried Walter von Tschirnhaus and Johann Friedrich Böttger successfully imitated Chinese hard paste and created the porcelain of Meissen. A way of life could be affected by one invention. The pendulum clock of the Dutch scientist Christiaan Huygens introduced an age of reliable timekeeping. Clocks were produced in great numbers, and Geneva's production of 5,000 timepieces a year was overtaken by 1680 by the clockmakers of both London and Paris. With groups of workers each responsible for a particular task, such as the making of wheels or the decoration of dials, specialization led to enhanced production, and in these elegant products of traditional craftsmanship the division of labour appeared.

ABSOLUTISM

Sovereigns and estates. Among European states of the High Renaissance, the republic of Venice provided the only important exception to princely rule. Following the court of Burgundy, where chivalric ideals vied with the self-indulgence of feast, joust, and hunt, Charles V, Francis I, and Henry VIII acted out the rites of kingship in sumptuous courts. Enormous Poland, particularly during the reign of Sigismund I (1506–48), and the miniature realms of Germany and Italy experienced the same type of regime and subscribed to the same enduring values that were to determine the principles of absolute monar-

chy. Appeal to God justified the valuable rights that the kings of France and Spain enjoyed over their churches and added sanction to hereditary right and constitutional authority. Henry VIII moved further when he broke with Rome and took to himself complete sovereignty.

Rebellion was always a threat. The skill of Elizabeth I (1558–1603) helped prevent England being torn apart by Roman Catholic and Puritan factions. Philip II (1555–98) failed to repress the continuing rebellion of what became a new state formed out of the northern Burgundian provinces. Neither Charles IX (1560–74) nor Henry III (1574–89) could stop the civil wars in which the Huguenots created an unassailable state within France. The failure of Maximilian I (1493–1519) to implement reforms had left the empire in poor shape to withstand the religious and political challenges of the Reformation. Such power as Charles V (1519–56) enjoyed in Germany was never enough to do more than contain schism within the bounds confirmed by the Treaty of Augsburg in 1555. Most of Hungary had been lost after the Turkish victory at Mohács in 1526. Imperial authority waned further under Maximilian II (1564–76) and Rudolf II (1576–1612). The terms of Augsburg were flouted as further church lands were secularized and Calvinism gained adherents, some in restless Bohemia. In these ways the stage was set for the subsequent wars and political developments.

With the tendency, characteristic of the Renaissance period, for sovereigns to enlarge their authority and assume new rights in justice and finance, went larger revenues, credit, and patronage. Princes fought with as little regard for economic consequences as their medieval precursors had shown. Ominously, the Italian wars had become part of a larger conflict, centring on the dynastic ambitions of the houses of Habsburg and Valois; similarly, the Reformation led to the formation of alliances whose objectives were not religious. The scale and expertise of diplomacy grew with the pretensions of sovereignty. The professional diplomat and permanent embassy, the regular soldier and standing army, served princes still generally free to act in their traditional spheres. But beyond them, in finance and government, what would be the balance of powers? From the answer to this question will come definition of the absolutism that is commonly seen as characteristic of the age.

The authority of a sovereign was exercised in a society of orders and corporations, each having duties and privileges. St. Paul's image of the Christian body was not difficult for a 17th-century European to understand; the organic society was a commonplace of political debate. The orders, as represented in estates or diets, were, first, the clergy; second, the nobility (represented with the lords spiritual in the English House of Lords); and, third, commoners. There were variations: upper and lower nobles were sometimes divided; certain towns represented the Third Estate, as in the Castilian Cortes; in Sweden, uniquely, there was an estate of peasants, whose successful effort to maintain their privilege was one component of Queen Christina's crisis of 1650. When, as in the 16th century, such institutions flourished, estates were held to represent not the whole population as individuals but the important elements—the "political nation." Even then the nobility tended to dominate. Their claim to represent all who dwelled on their estates was sounder in law and popular understanding than may appear to those accustomed to the idea of individual political rights.

In the empire, the estates were influential because they controlled the purse. Wherever monarchy was weak in relation to local elites, the diet tended to be used to further their interests. The Cortes of Aragon maintained into the 17th century the virtual immunity from taxation that was a significant factor in Spanish weakness. The strength of the representative institution was proportionate to that of the crown, which depended largely on the conditions of accession. The elective principle might be preserved in form, as in the English coronation service, but generally it had withered as the principle of heredity had been established. Where a succession was disputed, as between branches of the house of Vasa in Sweden after 1595, the need to gain the support of the privileged classes usually led to concessions being made to the body that they controlled. In Poland, where monarchy was elective, the Sejm exercised such power that successive kings, bound by conditions imposed at accession, found it hard to muster forces to defend their frontiers. The constitution remained unshakable even during the reign of John Sobieski (1674–96), hero of the relief of Vienna, who failed to secure the succession of his son. Under the Saxon kings Augustus II (1697–1733) and Augustus III (1734–63), foreign interference led to civil wars, but repeated and factious exercise of the veto rendered abortive all attempts to reform. It required the threat—and in 1772, the reality—of partition to give Stanisław II August Poniatowski (1764–95) sufficient support to effect reforms, but this came too late to save Poland.

At the other extreme were the Russian *zemsky sobor*, which fulfilled a last service to the tsars in expressing the landowners' demand for stricter laws after the disorders of 1648, and the Estates-General of France, where the size of the country meant that rulers preferred to deal with the smaller assemblies of provinces (*pays d'états*) lately incorporated into the realm, such as Languedoc and Brittany. They met regularly and had a permanent staff for raising taxes on property. With respect to the other provinces (*pays d'élection*), the crown had enjoyed the crucial advantage of an annual tax since 1439, when Charles VII successfully asserted the right to levy the personal *taille* without consent. When Richelieu tried to abolish one of the *pays d'état*, the Dauphiné, he met with resistance sufficient to deter him and successive ministers from tampering with this form of fiscal privilege. It survived until the Revolution: to ministers it was a deformity, to critics of the régime it provided at least one guarantee against arbitrary rule. The *zemsky sobor* had always been the creature of the ruler, characteristic of a society that knew nothing of fundamental laws or corporate rights. When it disappeared, the tsarist government was truly the despotism that the French feared but did not, except in particular cases, experience. When, in 1789, the Estates-General met for the first time since 1614, it abolished the privileged estates and corporations in the name of the freedom that they had claimed to protect. The age of natural human rights had dawned.

The experience of England, where Parliament played a vital part in the Reformation proceedings of Henry VIII's reign and thus gained in authority, shows that power could be shared between princes and representative bodies. On the Continent it was generally a different story. The Estates-General had been discredited because it had come to be seen as the instrument of faction. Religious differences had stimulated debate about the nature of authority, but extreme interpretations of the right of resistance, such as those that provoked the assassinations of William I the Silent, stadtholder of the Netherlands, in 1584 and Henry III of France in 1589, not only exposed the doctrine of tyrannicide but also pointed to the need for a regime strong enough to impose a religious solution. One such was the Edict of Nantes of 1598, which conceded to the Huguenots not only freedom of worship but also their own schools, law courts, and fortified towns. From the start the Edict constituted a challenge to monarchy and a test of its ability to govern. Richelieu's capture of La Rochelle, the most powerful Huguenot fortress and epicentre of disturbance, after a 14-month siege (1627–28) was therefore a landmark in the making of absolute monarchy, crucial for France and, because of its increasing power, for Europe as a whole.

Major forms of absolutism. *France.* Certain assumptions influenced the way in which the French state developed. The sovereign held power from God. He ruled in accordance with divine and natural justice and had an obligation to preserve the customary rights and liberties of his subjects. The diversity of laws and taxes meant that royal authority rested on a set of quasi-contractual relationships with the orders and bodies of the realm. Pervading all was a legalistic concern for form, precedence, and the customs that, according to the French jurist Guy Coquille, were the true civil laws. The efforts of successive ministers to create the semblance of a unitary state came less from dogma than from the need to overcome obsta-

cles to government and taxation. Absolutism was never a complete system to match the philosophy and rhetoric that set the king above the law, subject only to God, whom he represented on earth. For 60 years after the Fronde there was no serious challenge to the authority of the crown from either nobles or *parlement.* The idea of divine right, eloquently propounded by Bishop Jacques-Bénigne Bossuet and embodied in the palace and system of Versailles, may have strengthened the political consensus, but it did little to assist royal agents trying to please both Versailles and their own communities. Absolutism on the ground amounted to a series of running battles for political control. In the front line were the *intendants* (administrative officials), first used extensively by Richelieu, then, after their abolition during the Fronde, more systematically and with ever-widening responsibilities, by Louis XIV and his successors until 1789.

Throughout the ancien régime the absolutist ideal was flawed, its evolution stunted through persisting contradictions. The fiscal demands of the crown were incompatible with the constant need to stimulate trade and manufacturing enterprise; and only a resolute minister operating in peacetime, such as Colbert in the 1660s and Philibert Orry in the 1730s, could hope to achieve significant reforms. There was tension between the Roman Catholic ideal of uniformity and pragmatic views of the state's interest. In 1685 Louis XIV revoked the Edict of Nantes, a harsh if logical resolution of the question. It was what his Catholic subjects expected of him, but it proved damaging to the economy and to France's reputation. A further contradiction lay between measures to overcome the hostility of the nobles to the aggrandizement of the state and the need not to compromise state authority by conceding too much. Richelieu's actions, including the execution of the Duke of Montmorency for treason (1632), taught the lesson that no subject was beyond the reach of the law. Louis XIV's brilliant court drew the magnates to Versailles, where social eminence, patronage, and pensions compensated for loss of the power for which they had contended during the Fronde. It merely fortified the regime of privilege that defied fundamental reform to the end. There was another side to the politically advantageous sale of office. Capital was diverted that might better have been employed in business, and there was a vested interest in the status quo. For the mass of the nobility the enlargement of the army, quadrupled in the 17th century, provided an honourable career, but it also encouraged militarism and tempted the king and ministers to neglect the interests of the navy, commerce, and the colonies. When France intervened in the War of the Austrian Succession in 1741, the economic consequences undermined the regime. The achievements of the Bourbon government, with able ministers working in small, flexible councils, were impressive, even when undermined by weak kings such as Louis XV (1715–74) and Louis XVI (1774–92). In the 18th century, France acquired a fine network of roads, new harbours were built, and trade expanded; a lively culture was promoted by a prosperous bourgeoisie. It is an irony that the country that nurtured the philosophes was the least affected by the reforms they proposed, but it would have been a remarkable king who could have ruled with the courage and wisdom to enable his servants to overcome obstacles to government that were inherent in the system.

The empire. The character of Austrian absolutism was derived from a dual situation: with the exception of Maria Theresa, who was debarred by the Salic Law of Succession, the head of the house was also Holy Roman emperor. He directly ruled the family lands, comprising different parts of Austria stretching from Alpine valleys to the Danubian plain, which were mainly Roman Catholic and German; Bohemia, Moravia, and Silesia, which were mainly Slavic in race and language; a fraction of Hungary after the reconquest following the failure of the Turkish Siege of Vienna (1683); and Belgium and Milan (by the Peace of Rastatt in 1714). Each region provided a title and rights pertaining to that state, with an authority limited by the particular rights of its subjects. As an elected emperor, his sovereignty was of a different kind. In effect, the empire was a German confederation, though Bohemia was in and Prussia was outside it; the Mantuan succession affair (1627–31), when the emperor sought to arbitrate, recalls an obsolete Italian dimension. Each German state was self-governing and free to negotiate with foreign powers. Princes, both ecclesiastical and secular, enjoyed the right of representation in the Reichstag. The first of the three *curiae* in the Reichstag was the college of electors, who elected the emperor; the second comprised princes, counts, barons, and the ecclesiastical princes; and the third, the imperial free cities. The 45 dynastic principalities had 80 percent of the land and population; the 60 dynastic counties and lordships comprised only 3 percent. Some of the 60 imperial free cities were but villages. A thousand imperial knights, often landless, each claimed rights of landlordship amounting to sovereignty and owed allegiance only to the emperor in his capacity as president of the Reichstag. Numbers varied through wastage or amalgamation, but they convey the amorphous character of a confederation in which the emperor could only act effectively in concert with the princes, either individually or organized in administrative circles (*Kreis*). Bound by weak ties of allegiance and strong sentiment of nationality, this empire represented the world of medieval universalism with some aspects of the early modern state, without belonging wholly to either. Religious schism had created new frontiers and criteria for policy, such as could justify the elector palatine's decision to accept the crown of Bohemia from the rebels who precipitated the Thirty Years' War. The failure of the emperor Ferdinand II to enlarge his authority or enforce conformity led to the settlements of Westphalia in which his son, Ferdinand III, was forced to concede again the *cuius regio, eius religio* principle. Thereafter he and his successor, Leopold I, devoted their energies to increasing their authority over the family lands. It would be wrong, however, to assume that they, or even the 18th-century emperors, were powerless.

The political climate in which the empire operated was affected by the way universities dominated intellectual life and by trends within universities, in particular the development of doctrines of natural law and cameralism. German rulers respected the universities because the majority of their students became civil servants. With earnest religious spirit went an emphasis on the duty to work and obey. Even in Catholic states the spirit of the Aufklärung (Enlightenment) was pious and practical. Exponents of natural law, such as the philosopher-scientist Christian Wolff, advocated religious toleration but saw no need for constitutional safeguards: the ideal ruler was absolute. Such commitment to civic virtue explains both the development of the German state and the survival of the empire as a working institution. Territorial fragmentation meant a prince's combining his executive role with that of representative within the Reich: there could be no stimulus to the development of constitutional ideas. The German associated political liberty with the authority of his ruler. He was loyal to his own state, which was the "fatherland"; "abroad" was another state. When judgment was required, the prince would still go to the imperial court, the Reichskammergericht. There were limits to his loyalty. The emperor was expected to lead but could not always do so. So the authorities were ineffective, for example, in the face of Louis XIV's seizure of Strasbourg in 1681. Yet Louis found that German opinion was not to be underestimated; it contributed to his defeat in the War of the Grand Alliance.

Religious animosities persisted into the age of Gottfried Wilhelm Leibniz (1646–1716), but his rational approach and quest for religious unity corresponded to the popular yearning for stability. When interests were so delicately balanced, arbitration was preferable to aggression. The mechanism of the Reichskammergericht saved the counties of Isenburg and Solms from annexation by the ruler of Hesse-Darmstadt. More than a court of law, the Reichskammergericht functioned as a federal executive in matters of police, debts, bankruptcies, and tax claims. Small states such as Mainz could manage their affairs so as to turn enlightened ideas to good use, but it was the rulers of the larger states who held the keys to Germany's future, and they took note of the emperor; thus his am-

bivalent position was crucial. Frederick William I of Prussia accepted the ruling of Emperor Charles VI, confirming his right of succession to Berg. In return, the king guaranteed the Pragmatic Sanction, asserting the right of the emperor's daughter to succeed. Charles repudiated Prussia's claim, however, in 1738 when he made a treaty with France. In 1740, when both sovereigns died, Frederick II made Austria pay for this slight to his father. The War of the Austrian Succession followed his invasion of Silesia; that valuable Bohemian province remained at the heart of the Austro-Prussian conflict. Its final loss taught Maria Theresa and her advisers, notably Friedrich Haugwitz and Wenzel von Kaunitz, that they must imitate what they could not defeat. She created, in place of separate Austrian and Bohemian chancelleries, a more effective central administration based on the *Direktorium,* which her son Joseph (coruler from 1765, when he became emperor; sole ruler 1780–90) would develop in ruthless fashion. Maria Theresa respected the Roman Catholic tradition of her house, even while curtailing the powers of the church. Joseph pursued his mother's interests in education and a more productive economy and was concerned with equality of rights and the unity of his domains. Yet he joined in the partition of Poland for the reward of Galicia and showed so little regard for the rules of the empire that he was challenged by Frederick II over the Bavarian succession, which he had sought to manipulate to his advantage. After the ensuing Potato War (1778), the empire's days were numbered, though it required the contemptuous pragmatism of Napoleon to abolish it (1806).

Prussia. Frederick II had inherited a style of absolute government that owed much to the peculiar circumstances of Brandenburg-Prussia as it emerged from the Thirty Years' War. Lacking natural frontiers and war-ravaged when Frederick William inherited the electorate in 1640, Brandenburg had little more than the prestige of the ancient house of Hohenzollern. The diplomacy of Jules Cardinal Mazarin contributed to the acquisition (1648) of East Pomerania, Magdeburg, and Minden, and war between Sweden and Poland brought sovereignty over East Prussia, formerly held as a fief from Poland. A deal with the Junkers at the Recess of 1653, which secured a regular subsidy in return for a guarantee of their social rights, was the foundation of an increasingly absolute rule. He overcame by force the resistance of the diet of Prussia in 1660: as he became more secure economically, militarily, and bureaucratically, he depended less on his diets. So was established the Prussian model: an aristocracy of service and a bureaucracy harnessed to military needs. The Great Elector's son became King Frederick I of Prussia when he pledged support to the emperor's cause (1701). His son, Frederick William (1713–40), completed the centralization of authority and created an army sustained by careful stewardship of the economy. Personally directing a larger army in wars of aggression and survival, Frederick the Great (1740–86) came close to ruining his state; its survival testifies to the success of his father. Of course Frederick left his own impress on government. He should not be judged by his essays in enlightened philosophy or even by new mechanisms of government, but by the spirit he inspired. He lived out his precept that the sovereign should be the first servant of the state. All was ordered so as to eliminate obstacles to the executive will. Much was achieved: the restoration of Prussia and the establishment of an industrial base, in particular the exploitation of the new Silesian resources. Legal rights and freedom of thought were secure so long as they did not conflict with the interest of the state. A monument to his reign, completed five years after his death in 1786, was the Allgemeine Landrecht, the greatest codification of German law. Perhaps his greatest civil achievement was the stability that made such a striking contrast with the turbulence in Habsburg lands under Joseph II.

Variations on the absolutist theme. *Sweden.* In Sweden the Konungaförsäkran ("King's Assurance"), which was imposed at the accession of the young Gustav II Adolf in 1611 and which formally made him dependent for all important decisions on the Råd (council) and Riksdag (diet), was no hindrance to him and his chancellor, Axel Oxenstierna, in executing a bold foreign policy and important domestic reforms. Queen Christina, a minor until 1644, experienced a constitutional crisis (1650) in the aftermath of the Thirty Years' War, from which Sweden had gained German lands, notably West Pomerania and Bremen. She extricated herself with finesse, then abdicated (1654). Charles X sought a military solution to the threat of encirclement by invading Poland and, more successfully, Denmark, but he left the kingdom to his four-year-old son (1660) with problems of political authority unresolved. When he came of age, Charles XI won respect for his courage in war and established an absolutism beyond doubt or precedent by persuading the Riksdag to accept an extreme definition of his powers (1680). Then he carried out the drastic recovery of alienated royal lands. With novel powers went military strength based on a corps of farmer-soldiers from the recovered land. Tempting authority awaited Charles XII (1697–1718), but there was also a menacing coalition. Perhaps decline was inevitable, for Sweden's greatness had been a tour de force, but Charles XII's onslaughts on Poland and Russia risked the state as well as the army which he commanded so brilliantly. Even after the Russian victory at Poltava (1709) and Charles's exile in Turkey, Sweden's resistance testified to the soundness of government. When Charles died fighting in Norway, Sweden had lost its place in Germany and a third of its adult population. An aristocratic reaction led to a period of limited monarchy. Decisions were made by committees of the Riksdag, influenced by party struggle, like that of the Hats and Caps at mid-century. Gustav III carried out a coup in 1774 that restored greater power to the sovereign, but there was no break in two great traditions: conscientious sovereign and responsible nobility.

Denmark. Denmark also had turned in the absolutist direction. Enforced withdrawal from the Thirty Years' War (in 1629) may not have been a disaster for Denmark, but the loss of the Scanian provinces to Sweden (1658) was—loss of control of the Sound was a standing temptation to go to war again. Events in Denmark exemplify on a small scale what was happening throughout Europe when princes built from war's wreckage, exploiting the yearning for direction and benefiting from the decay of a society that no longer provided good order. The smaller the country, the stronger the ruler's prospect of asserting his will. As if responding to Hobbes's formula for absolute monarchy, the estates declared King Frederick III supreme head on earth, elevated above all human laws (1661). Reforms followed under the statesmen Hannibal Sehested and Peter Schumacker: a new code of law was promulgated; mercantilist measures fostered trade; and Copenhagen flourished. Danes accepted with docility the autocratic rule of the house of Oldenburg, but the peasantry suffered from the spread of a German style of landownership. Frederick IV cared much about their souls, and his son Christian VI provided for their schooling, but a decree of 1733 tied peasants to their estates from the age of 14 to 36. Frederick V was fortunate to have capable ministers, notably Andreas Bernstorff, who was mainly responsible for the acquisition of long-disputed Schleswig and Holstein. His son Christian VII ruled until 1808; yet his reign is best known for his confinement under Johan Struensee and for the latter's liberal reforms. In the two years before his downfall in 1772, more than 1,000 laws were passed, including measures that have left their mark on Danish society to this day. The episode showed the perils as well as benefits of enlightened absolutism when a king or his subject acquired the power to do as he pleased.

Spain. The Iberian Peninsula provides further illustration of the absolutist theme. Historians do not agree about the nature or precise extent of Spain's decline, but there is agreement that it did occur, that it was most pronounced at mid-century, and that its causes may be traced not only to the reign of Philip II (1556–98), the overextended champion of Roman Catholic and Spanish hegemony, but also to the social and political structure of the Spanish states of Castile, Aragon, Portugal, Milan, Naples, the Netherlands, and Franche-Comté. The constitutions of these states reflected the personal nature of the original union of crowns (1479) and of subsequent acquisitions. Castile received the

largest share of the prosperity that came with silver bullion from the New World but suffered the worst consequences when Mexico and Peru became self-sufficient. Bullion imports fell sharply; trade with the rest of Europe was severely imbalanced; and the weight of taxation fell largely on Castile. The effort of Philip IV's chief minister, the Count de Olivares, to ensure greater equality of contribution through the union of arms was one factor in the revolts of Catalonia and Portugal (1640). In 1659 Spain had to cede Roussillon, Cerdagne, and Artois to France; and in 1667–68 the Flemish forts could put up no fight against the invading French. Despite a partial recovery in the 1680s under the intelligent direction of the Duke de Medinaceli and Manuel Oropesa, Spain was the object of humiliating partition treaties. In 1700 Charles II had bequeathed the entire inheritance to Philip of Anjou, Louis XIV's grandson. A foundation for recovery was laid early in the reign of Philip V, when outlying provinces lost their privileges and acquired a tax system based on ability to pay and a French-style *intendente* to enforce it. The pace of reform accelerated with the accession of Charles III in 1759. He was no radical, but he backed ministers who were, such as the Count de Floridablanca and the Count de Campomanes. A national bank, agricultural improvements, and new roads, factories, and hospitals witnessed to the efforts of this benevolent autocrat to overcome the Spanish habit of condemning everything new.

Portugal. Neighbouring Portugal acquired independence in 1668 after revolt and war protracted by the stubborn determination of Philip IV to maintain his patrimony. This small country had suffered since 1580 from its Spanish connection. Resentment at the loss of part of Brazil and most of its Far Eastern colonies had been a major cause of the revolt. The Portuguese did not see their interests as lying with Spain's in partnership with Austria and war against France and Holland. The reorientation of foreign policy and alliance with England by the Methuen Treaty (1703) brought respite rather than restoration. When Sebastien Pombal became the virtual dictator of Portugal as chief minister of Joseph I, he instituted drastic change. If the rebuilding of Lisbon after the great earthquake of 1755 is his memorial, he is also remembered for his assault on the Jesuits; Spain, France, and Austria followed his lead in expelling the powerful religious order, whose grip on education seemed to "enlightened" minds to obstruct progress.

Britain. The Marquês de Pombal was inspired by what he had seen in London, and it was in Great Britain (as it became after the Act of Union with Scotland in 1707) that the entrepreneurial spirit was least restricted and most influential in government and society. By the accession of James I in 1603, there had already been a significant divergence from the Continental pattern. The 17th century saw recurring conflict between the crown—more absolute in language than in action—and Parliament. Elected on a narrow, uneven suffrage, it represented privileged interests rather than individuals; it was much concerned with legal precedents and rights. Charles I tried to rule without Parliament from 1629 to 1639, but he alienated powerful interests and, by trying to impose the Anglican prayer book on Scotland, blundered into a civil war that resulted in his overthrow and subsequent execution (1649). Experiments in parliamentary rule culminated in the protectorate of Oliver Cromwell; after his death (1658), Charles II was restored (1660) on financial terms intended to restrict his freedom of maneuver. After a crisis (1678–81) in which the Whigs, led by Lord Shaftesbury, exploited popular prejudice against Roman Catholicism and France to check his absolutist tendency, he recovered the initiative. However, the brief reign of James II (1685–88) justified the fears of those who had sought to exclude him. Policies designed to relieve Roman Catholics antagonized the leaders of the monarchist Anglican church as well as the families who thought that they had the right to manage the state. The Glorious Revolution brought the Dutch stadtholder to the throne as William III (1689–1702). The intense political struggle left a fund of theory and experience on which 18th-century statesmen could draw. There was, however, no written constitution and only a few statutory limitations. Monarchy retained the power to appoint ministers, make foreign policy, and to manage and direct the army. The Bill of Rights (1689) effectively abolished the suspending and dispensing powers, but William III pursued his European policy with an enlarged army, funded by a new land tax and by loans. Conflict grew between the Whigs and Tories, intensified by the controversy over "Marlborough's war" in the reign of Queen Anne (1702–14). The Triennial Act (1694) ensured elections every three years, and the Act of Settlement (1701) sealed the supremacy of the common law by limiting the king's power to dismiss judges. The accession of George I in 1714 did not lead immediately to stability. The union with Scotland (1707) had created strains; and Jacobitism remained a threat after the defeat of James Edward Stuart's rising of 1715—until the defeat of his son Charles Edward at Culloden in 1746, it was a focus for the discontented. But investors in government funds had a growing stake in the survival of the dynasty.

When George I gave up attending Cabinet meetings, he cleared the way for the Privy Council's displacement by the small cabinet council, and the evolution, in the person of Robert Walpole, first lord of the Treasury from 1721 to 1742, of a "prime minister." Relations between minister and king amounted to a dialogue between the concepts of ministerial responsibility and royal prerogative. Ministers exercised powers legally vested in the monarch; they also were accountable to Parliament. Yet the king could still appoint and dismiss them. Inevitably tensions resulted. The prime minister's right to select fellow ministers did not go unchallenged, but the reluctance of both George I and George II to master the intricacies of patronage, and the skill of Walpole and Newcastle in political management, ensured that the shift in the balance of power in 1688 was irreversible. A centralized legislature coexisted with a decentralized administration. The theme of centre versus provinces, characteristic of other countries, took on a new form as court patronage became the prime element in political management. Most legislation was concerned not with legal or moral principles but with administrative details. Policy tended to emerge from agreement between king and ministers. The royal veto on legislation was never employed after 1708, no government lost a general election, and nearly every Parliament lasted its full term. Locke's dictum that government has no other end but the preservation of property was an apt text for the British ancien régime, which was dominated by the church and the aristocracy. Even those 200,000 Englishmen who had the vote could be disfranchised by the common practice of an arranged election. In 1747 only three county and 62 borough elections were contested. The tone was set by the Septennial Act (1716), which doubled the life of Parliaments and the value of patronage.

The office of prime minister

Holland. The English ambassador Sir George Downing in 1664 described the constitution of the United Provinces as "such a shattered and divided thing." Louis XIV assumed wrongly, in 1672, that the mercantile republic would prove no match for his armies. Experience had taught the English to respect Dutch naval strength as much as they envied its commercial wealth. Foreign attitudes were ambivalent because this small state was not only the newest but also the richest per capita and quite different from any other. The nation of seamen and merchants was also the nation of Rembrandt, Huygens, and Spinoza; culture and the trading empire were inseparable. After 1572 the Dutch proved that they could hold their own in war. Criticism of the structure of government seems therefore to be wide of the mark. In the development of Amsterdam, private enterprise and civic regulation coexisted in creative harmony; so too the state was effective without impinging on the quality of individual lives. The federal republic, so the Dutch believed, guarded religion, lands, and liberties. The price was paid by the Spanish southern provinces, which were drained of vitality by emigration to the north, and by the decay of the trade and manufacturing that had given Antwerp a commanding financial position.

The constitution of the United Provinces reflected its Burgundian antecedents in civic pride and its concern for form and precedence. Sovereignty lay with the seven

provinces separately; in each the States ruled, and in the States the representatives of the towns were dominant. Since action required a unanimous vote, issues were commonly referred back to town corporations. Only in Friesland did peasants have a voice. The States-General dealt with diplomatic and military measures and with taxes. Its members were ambassadors, closely tied by their instructions. Like contemporary Poles and Germans, the Dutch were separatists at heart, but what was lacking in those countries existed in the United Provinces—one province to lead the rest. Holland assumed, and because of its wealth the rest could not deny, that right. War was again the crucial factor.

One side of the balance was represented by the house of Orange. Maurice of Nassau (1584–1625) and Frederick Henry (1625–47) controlled policy and military campaigns through their virtual monopoly of the office of stadtholder in separate provinces. Monarchs without title, they intermarried with the Protestant dynasties: William III, the grandson of Charles I of England and great-grandson of Henry IV of France, married Mary Stuart and became, with her, joint sovereign of England in 1689. The other side, vigilant for peace, trade, and lower taxes, was represented at its best by Johan de Witt, pensionary of Holland (1653–72). He was murdered during the French invasion of 1672, which brought William III to power. Enlightened oligarchy had little appeal for the poor or tolerance for the Calvinist clergy. Such violence exposed underlying tensions. In 1619 the veteran statesman Johann van Oldenbarneveldt was executed, as much because of the political implications of his liberal stance as for his Arminian views. Holland's open society depended on the commercial values of a magistracy versed in finance and state policy. In 1650 the young stadtholder William II attempted a coup against Amsterdam, the outcome of which was uncertain. His sudden death settled the issue in favour of a period of rule without stadtholders. In 1689 William III's elevation led to consolidation of the republican regime. In 1747, William IV enjoyed popular support for a program of civic reform. As stadtholder of all seven provinces he had concentrated powers, but little was achieved. Not until 1815 was the logical conclusion reached with the establishment of William I as king.

Russia. Successive elective kings of Poland failed to overcome the inherent weaknesses of the state, and the belated reforms of Stanisław II served only to provoke the final dismemberments of 1793 and 1795. Russia was a prime beneficiary, having long shown that vast size was not incompatible with strong rule. Such an outcome would not have seemed probable in 1648, when revolt in the Ukraine led to Russian "protection" and the beginning of that process of expansion which was to create an empire. The open character of Russia's boundless lands militated against two processes characteristic of Western society—the growth of cherished rights in distinct, rooted communities and that of central authority, adept in the techniques of government. The validity of the state depended on its ability to make the peasant cultivate the soil. If the nobility were to serve the state, they must be served on the land. Serfdom was a logical development in a society that knew nothing of rights. The feudal concept of fealty, the validity of contract, and the idea of liberty as the creation of law were unknown. German immigrants found no provincial estates, municipal corporations, or craft guilds. Merchants were state functionaries. Absolutism was implicit in the physical conditions and early evolution of Russian society. It could only become a force for building a state comparable to those of the West under a ruler strong enough to challenge traditional ways. This was to be the role of Alexis I (1645–76) and then, more violently, of Peter I (1689–1725).

When the Romanov dynasty emerged in 1613 with Tsar Michael, the formula for continued power was similar to that of the Great Elector in Brandenburg: the common interest of ruler and gentry enabled Alexis to dispense with the *zemsky sobor.* The great code of 1649 affirmed the rights of the state over a society that was to be frozen in its existing shape. The tsars were haunted by the fear that the state would disintegrate. The acquisition of the Ukraine led directly to the revolt of Stenka Razin (1670), which flared up because of the discontent of the serfs. The Russian people had been driven underground; their passivity could not be assumed. There was also a threatening religious dimension in the shape of the Old Believers. Rallying in reaction to the minor reforms of the patriarch Nikon, they came to express a general attachment to old Russia. This was as dangerous to the state when it inspired passive resistance to change as when it provoked revolt, such as that of the *streltsy,* the privileged household troops, whom Peter purged in 1698. Peter's reforms of Russian government must be set against the military weakness revealed by the Swedish victory at Narva (1700), the grotesque disorder of government as exercised by more than 40 councils, the lack of an educated class of potential bureaucrats, and a primitive economy untouched by Western technology. His domestic policies can then be seen as expedients informed by a patchy vision of Western methods and manners. Catherine II studied his papers and said, "He did not know what laws were necessary for the state." Yet, without Peter's relentless drive to create a military power based on compulsory service, Catherine might have been in no position to carry out any reforms herself. His Table of Ranks (1722) graded society in three categories—court, government, and army. The first eight military grades, all commissioned officers, automatically became gentry. Obligatory service was modified by later rulers and abolished by Peter III (1762). By then the army had sufficient attraction: the officer caste was secure.

Meanwhile, the bureaucracy exemplified the style of a military police. The uniformed official, rule book in hand, was typical of St. Petersburg government until 1917. Peter's new capital, an outrageous defiance of Muscovite tradition, symbolized the chasm that separated the Westernized elite from the illiterate masses. It housed the senate, set up in 1711, and the nine colleges that replaced the 40 councils. There also was the *oberprokuror,* responsible for the Most Holy Synod, which exercised authority over the church in place of the patriarch. Peter could control the institution; to touch the souls or change the manners of his people was another matter. A Russian was reluctant to lose his beard because God had a beard; a townsman could be executed for leaving his ward; a nobleman could not marry without producing a certificate to show that he could read. With a punitive tax, Peter might persuade Russians to shave and adopt Western breeches and jacket, but he could not trust the free spirit that he admired in England nor expect market, capital, or skills to grow by themselves. So a stream of edicts commanded and explained. State action could be effective—iron foundries, utilizing Russia's greatest natural resource, timber, contributed to the country's favourable trade balance—but nearly all Peter's schools collapsed after his death, and his navy rotted at its moorings.

After Peter there were six rulers in 37 years. Two of the predecessors of Catherine II (1762–95) had been deposed—one of them, her husband Peter III, with her connivance. Along with the instability exemplified by the palace coup of 1741, when the guards regiments brought Elizabeth to the throne, went an aristocratic reaction against centralist government, particularly loathsome as exercised under Anna (1730–40). Elizabeth's tendency to delegate power to favoured grandees encouraged aristocratic pretension, though it did lead to some enlightened measures. With the accession of the German-born Catherine Russians encountered the Enlightenment as a set of ideas and a program of reforms. Since the latter were mostly shelved, questions arise about the sincerity of the royal author of the *Nakaz,* instructions for the members of the Legislative Commission (1767–68). If Catherine still hoped that enlightened reforms, even the abolition of serfdom, were possible after the Commission's muddle, the revolt of Yemelyan Pugachov (1773–75) brought her back to the fundamental questions of security. His challenge to the autocracy was countered by military might, but not before 3,000,000 peasants had become involved and 3,000 officials and gentry had been murdered. The underlying problem remained. The tired soil of old Russia would not long be able to feed the growing population.

Trapped between the low yield of agriculture and their rising debts, the gentry wanted to increase dues. The drive for new lands, culminating in the acquisition of the Crimea (1783), increased the difficulties of control. Empirical and authoritarian, Catherine sought to strengthen government while giving the gentry a share and a voice. The Great Reform of 1775 divided the country into 50 *guberni*. The *dvoriane* were allowed some high posts, by election, on the boards set up to manage local schools and hospitals. They were allowed to meet in assembly. It was more than most French nobles could do: indeed, French demands for assemblies were a prelude to revolution. But as in the case of towns, by the Municipal Reform (1785), she gave only the appearance of self-government. Governors were left with almost unbounded powers. Like Frederick the Great, Catherine disappointed the philosophes, but the development of Russia took place within a framework of order. European events in the last years of Catherine's life and Russian history, before and since, testify to the magnitude of her achievement.

Absolute monarchy had evolved out of conflicts within and challenges outside the state, notably that of war, whose recurring pressures had a self-reinforcing effect. The absolutist ideal was potent, and the rhetoric voiced genuine feeling. The sovereign who envisaged himself as God's Lieutenant or First Servant of the State was responding to those who had found traditional constitutions wanting and whose classical education and religious upbringing had schooled them to look for strong rule within a hierarchical system. For more than 150 years, the upper classes of continental Europe were disposed to accept the ethos of absolutism. They would continue to do so only if the tensions within the system could be resolved and if the state were to prove able to accommodate the expectations of the rising bourgeoisie and the potentially unsettling ideas of the Enlightenment.

THE ENLIGHTENMENT

The Enlightenment was both a movement and a state of mind. The term represents a phase in the intellectual history of Europe, but it also serves to define programs of reform in which influential literati, inspired by a common faith in the possibility of a better world, outlined specific targets for criticism and proposals for action. The special significance of the Enlightenment lies in its combination of principle and pragmatism. Consequently, it still engenders controversy about its character and achievements. Two main questions and, relating to each, two schools of thought can be identified. Was the Enlightenment the preserve of an elite, centred on Paris, or a broad current of opinion that the philosophes, to some extent, represented and led? Was it primarily a French movement, having therefore a degree of coherence, or an international phenomenon, having as many facets as there were countries affected? Although most modern interpreters incline to the latter view in both cases, there is still a case for the French emphasis, given the genius of a number of the philosophes and their associates. Unlike other terms applied by historians to describe a phenomenon that they see more clearly than could contemporaries, it was used and cherished by those who believed in the power of mind to liberate and improve. Bernard de Fontenelle, popularizer of the scientific discoveries that contributed to the climate of optimism, wrote in 1702 anticipating "a century which will become more enlightened day by day, so that all previous centuries will be lost in darkness by comparison." Reviewing the experience in 1784, Immanuel Kant saw an emancipation from superstition and ignorance as having been the essential characteristic of the Enlightenment.

Before Kant's death the spirit of the *siècle de lumière* (literally, "century of light") had been spurned by Romantic idealists, its confidence in man's sense of what was right and good mocked by revolutionary terror and dictatorship, and its rationalism decried as being complacent or downright inhumane. Even its achievements were critically endangered by the militant nationalism of the 19th century. Yet much of the tenor of the Enlightenment did survive in the liberalism, toleration, and respect for law that have persisted in European society. There was therefore no abrupt end or reversal of enlightened values.

Nor had there been such a sudden beginning as is conveyed by the critic Paul Hazard's celebrated aphorism: "One moment the French thought like Bossuet; the next moment like Voltaire." The perceptions and propaganda of the philosophes have led historians to locate the Age of Reason within the 18th century or, more comprehensively, between the two revolutions—the English of 1688 and the French of 1789—but in conception it should be traced to the humanism of the Renaissance, which encouraged scholarly interest in classical texts and values. It was formed by the complementary methods of the Scientific Revolution, the rational and the empirical. Its adolescence belongs to the two decades before and after 1700 when writers such as Jonathan Swift were employing "the artillery of words" to impress the secular intelligentsia created by the growth in affluence, literacy, and publishing. Ideas and beliefs were tested wherever reason and research could challenge traditional authority.

Sources of Enlightenment thought. In a cosmopolitan culture it was the preeminence of the French language that enabled Frenchmen of the 17th century to lay the foundations of cultural ascendancy and encouraged the philosophes to act as the tutors of 18th-century Europe. The notion of a realm of philosophy superior to sectarian or national concerns facilitated the transmission of ideas. "I flatter myself," wrote Denis Diderot to the Scottish philosopher David Hume, "that I am, like you, citizen of the great city of the world." "A philosopher," wrote Edward Gibbon, "may consider Europe as a great republic, whose various inhabitants have attained almost the same level of politeness and cultivation." This magisterial pronouncement by the author of *The Decline and Fall of the Roman Empire* (1776–88) recalls the common source: the knowledge of classical literature.

The scholars of the Enlightenment recognized a joint inheritance, Christian as well as classical. In rejecting, or at least reinterpreting, the one and plundering the other, they had the confidence of those who believed they were masters of their destiny. They felt an affinity with the classical world and saluted the achievement of the Greeks, who discovered a regularity in nature and its governing principle, the reasoning mind, as well as that of the Romans, who adopted Hellenic culture while contributing a new order and style: on their law was founded much of church and civil law. Steeped in the ideas and language of the classics but unsettled in beliefs, some Enlightenment thinkers found an alternative to Christian faith in the form of a neo-paganism. The morality was based on reason; the literature, art, and architecture were already supplying rules and standards for educated taste.

The first chapter of Voltaire's *Siècle de Louis XIV* specified the "four happy ages": the centuries of Pericles and Plato, of Cicero and Caesar, of the Medicean Renaissance, and, appositely, of Louis XIV. The contrast is with "the ages of belief," which were wretched and backward. Whether denouncing Gothic taste or clerical fanaticism, writers of the Enlightenment constantly resort to images of relapse and revival. Typically, Jean d'Alembert wrote in the *Preliminary Discourse to the Encyclopédie* of a revival of letters, regeneration of ideas, and return to reason and good taste. The philosophes knew enough to be sure that they were entering a new golden age through rediscovery of the old but not enough to have misgivings about a reading of history which, being grounded in a culture that had self-evident value, provided ammunition for the secular crusade.

The role of science and mathematics. "The new philosophy puts all in doubt," wrote the poet John Donne. Early 17th-century poetry and drama abounded in expressions of confusion and dismay about the world, God, and man. The gently questioning essays of the 16th-century French philosopher Michel de Montaigne, musing on human folly and fanaticism, continued to be popular long after his time, for they were no less relevant to the generation that suffered from the Thirty Years' War. Unsettling scientific views were gaining a hold. As the new astronomy of Copernicus and Galileo, with its heliocentric view, was accepted, the firm association between religious beliefs,

moral principles, and the traditional scheme of nature was shaken. In this process, mathematics occupied the central position. It was, in the words of René Descartes, "the general science which should explain all that can be known about quantity and measure, considered independently of any application to a particular subject." It enabled its practitioners to bridge gaps between speculation and reasonable certainty: Johannes Kepler thus proceeded from his study of conic sections to the laws of planetary motion. When, however, Fontenelle wrote of Descartes, "Sometimes one man gives the tone to a whole century," it was not merely of his mathematics that he was thinking. It was the system and philosophy that Descartes derived from the application of mathematical reasoning to the mysteries of the world—all that is meant by Cartesianism—which was so influential. The method expounded in his *Discourse on Method* (1637) was one of doubt: all was uncertain until established by reasoning from self-evident propositions, on principles analogous to those of geometry. It was serviceable in all areas of study. There was a mechanistic model for all living things.

Trustees of the Science Museum, London



Astronomers at work with a quadrant (left) and a telescope (right) at the Royal Observatory, Greenwich, Eng., founded by John Flamsteed in 1675. In the Science Museum, London.

A different track had been pursued by Francis Bacon, the great English lawyer and savant, whose influence eventually proved as great as that of Descartes. He called for a new science, to be based on organized and collaborative experiment with a systematic recording of results. General laws could be established only when research had produced enough data and then by inductive reasoning, which, as described in his *Novum Organum* (1620), derives from "particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all." These must be tried and proved by further experiments. Bacon's method could lead to the accumulation of knowledge. It also was self-correcting. Indeed, it was in some ways modern in its practical emphasis. Significantly, whereas the devout humanist Thomas More had placed his *Utopia* in a remote setting, Bacon put *New Atlantis* (1627) in the future. "Knowledge is power," he said, perhaps unoriginally but with the conviction that went with a vision of mankind gaining mastery over nature. Thus were established the two poles of scientific endeavour, the rational and the empirical, between which enlightened man was to map the ground for a better world.

Bacon's inductive method is flawed through his insufficient emphasis on hypothesis. Descartes was on strong ground when he maintained that philosophy must proceed from what is definable to what is complex and uncertain. He wrote in French rather than the customary Latin so as to exploit its value as a vehicle for clear and logical expression and to reach a wider audience. Cartesian rationalism, as applied to theology, for example by Nicholas Malebranche, who set out to refute the pantheism of Benedict de Spinoza, was a powerful solvent of traditional belief: God was made subservient to reason. While Descartes maintained his hold on French opinion, across the Channel Isaac Newton, a prodigious mathematician and a resourceful and disciplined experimenter, was mounting a crucial challenge. His *Philosophiae Naturalis Principia Mathematica* (1687; *Mathematical Principles of Natural Philosophy*) ranks with the *Discourse on Method* in authority and influence as a peak in the 17th-century quest for truth. Newton did not break completely with Descartes and remained faithful to the latter's fundamental idea of the universe as a machine. But Newton's machine operated according to a series of laws, the essence of which was that the principle of gravitation was everywhere present and efficient. The onus was on the Cartesians to show not only that their mechanics gave a truer explanation but also that their methods were sounder. Christiaan Huygens was both a loyal disciple of Descartes and a formidable mathematician and inventor in his own right, who had worked out the first tenable theory of centrifugal force. His dilemma is instructive. He acknowledged that Newton's assumption of forces acting between members of the solar system was justified by the correct conclusions he drew from it, but he would not go on to accept that attraction was affecting every pair of particles, however minute. When Newton identified gravitation as a property inherent in corporeal matter, Huygens thought that absurd and looked for an agent acting constantly according to certain laws. Some believed that Newton was returning to "occult" qualities. Eccentricities apart, his views were not easy to grasp; those who actually read the *Principia* found it painfully difficult. Cartesianism was more accessible and appealing.

The contribution of Newton

Gradually, however, Newton's work won understanding. One medium, ironically, was an outstanding textbook of Cartesian physics, Jacques Rohault's *Traité de physique* (1671), with detailed notes setting out Newton's case. In 1732 Pierre-Louis de Mauperthuis put the Cartesians on the defensive by his defense of Newton's right to employ a principle the cause of which was yet unknown. In 1734, in his *Philosophical Letters,* Voltaire introduced Newton as the "destroyer of the system of Descartes." His authority clinched the issue. Newton's physics was justified by its successful application in different fields. The return of Halley's comet was accurately predicted. Charles Coulomb's torsion balance proved that Newton's law of inverse squares was valid for electromagnetic attraction. Cartesianism reduced nature to a set of habits within a world of rules; the new attitude took note of accidents and circumstances. Observation and experiment revealed nature as untidy, unpredictable—a tangle of conflicting forces. In classical theory, reason was presumed to be common to all human beings and its laws immutable. In Enlightenment Europe, however, there was a growing impatience with systems. The most creative of scientists, such as Boyle, Harvey, and Leeuwenhoek, found sufficient momentum for discovery on science's front line. The controversy was creative because both rational and empirical methods were essential to progress. Like the literary battle between the "ancients" and the "moderns" or the theological battle between Jesuits and Jansenists, the scientific debate was a school of advocacy.

If Newton was supremely important among those who contributed to the climate of the Enlightenment, it is because his new system offered certainties in a world of doubts. The belief spread that Newton had explained forever how the universe worked. This cautious, devout empiricist lent the imprint of genius to the great idea of the Enlightenment: that man, guided by the light of reason, could explain all natural phenomena and could embark on the study of his own place in a world that was no longer mysterious. Yet he might otherwise have been aware more of disintegration than of progress or of theories demolished than of truths established. This was true even within the expanding field of the physical sciences. To gauge the mood of the world of intellect and fashion, of French salons or of such institutions as the Royal Society, it is essential to understand what constituted the crisis in the European mind of the late 17th century.

At the heart of the crisis was the critical examination of

Christian faith, its foundations in the Bible, and the authority embodied in the church. In 1647 Pierre Gassendi had revived the atomistic philosophy of Lucretius, as outlined in *On the Nature of Things*. He insisted on the Divine Providence behind Epicurus' atoms and voids. Critical examination could not fail to be unsettling because the Christian view was not confined to questions of personal belief and morals, or even history, but comprehended the entire nature of God's world. The impact of scientific research must be weighed in the wider context of an intellectual revolution. Different kinds of learning were not then as sharply distinguished, because of their appropriate disciplines and terminology, as they are in an age of specialization. At that time philomaths could still be polymaths. Newton's contemporary, Gottfried Wilhelm Leibniz—whose principal contribution to philosophy was that substance exists only in the form of monads, each of which obeys the laws of its own self-determined development while remaining in complete accord with all the rest—influenced his age by concluding that since God contrived the universal harmony this world must be the best of all possible worlds. He also proposed legal reforms, invented a calculating machine, devised a method of the calculus independent of Newton's, improved the drainage of mines, and laboured for the reunification of the Roman Catholic and Lutheran churches.

The influence of Locke. The writing of John Locke, familiar to the French long before the eventual victory of his kind of empiricism, further reveals the range of interests that an educated man might pursue and its value in the outcome: discrimination, shrewdness, and originality. The journal of Locke's travels in France (1675–79) is studded with notes on botany, zoology, medicine, weather, instruments of all kinds, and statistics, especially those concerned with prices and taxes. It is a telling introduction to the world of the Enlightenment, in which the possible was always as important as the ideal and physics could be more important than metaphysics. Locke spent the years from 1683 to 1689 in Holland, in refuge from high royalism. There he associated with other literary exiles, who were united in abhorrence of Louis XIV's religious policies, which culminated in the revocation of the Edict of Nantes (1685) and the flight of more than 200,000 Huguenots. During this time Locke wrote the *Essay on Toleration* (1689). The coincidence of the Huguenot dispersion with the English revolution of 1688–89 meant a cross-fertilizing debate in a society that had lost its bearings. The avant-garde accepted Locke's idea that the people had a sovereign power and that the prince was merely a delegate. His *Second Treatise of Civil Government* (1690) offered a theoretical justification for a contractual view of monarchy on the basis of a revocable agreement between ruler and ruled. It was, however, his writings about education, toleration, and morality that were most influential among the philosophes, for whom his political theories could be only of academic interest. Locke was the first to treat philosophy as purely critical inquiry, having its own problems but essentially similar to other sciences. Voltaire admired what Locke called his "historical plain method" because he had not written "a romance of the soul" but offered "a history of it." The avowed object of his *Essay Concerning Human Understanding* (1690) was "to inquire into the original, certainty, and extent of human knowledge; together with the grounds and degrees of belief, opinion, and assent." For Locke, the mind derives the materials of reason and knowledge from experience. Unlike Descartes' view that man could have innate ideas, in Locke's system knowledge consists of ideas imprinted on the mind through observation of external objects and reflection on the evidence provided by the senses. Moral values, Locke held, are derived from sensations of pleasure or pain, the mind labeling good what experience shows to give pleasure. There are no innate ideas; there is no innate depravity.

Though he suggested that souls were born without the idea of God, Locke did not reject Christianity. Sensationalism, he held, was a God-given principle that, properly followed, would lead to conduct that was ethically sound. He had, however, opened a way to disciples who proceeded to conclusions that might have been far from the master's mind. One such was the Irish bishop George Berkeley who affirmed, in his *Treatise on the Principles of Human Knowledge* (1710), that there was no proof that matter existed beyond the idea of it in the mind. Most philosophers after Descartes decided the question of the dualism of mind and matter by adopting a materialist position; whereas they eliminated mind, Berkeley eliminated matter—and he was therefore neglected. Locke was perhaps more scientific and certainly more in tune with the intellectual and practical concerns of the age. Voltaire presented Locke as the advocate of rational faith and of sensationalist psychology; Locke's posthumous success was assured. In the debate over moral values, Locke provided a new argument for toleration. Beliefs, like other human differences, were largely the product of environment. Did it not therefore follow that moral improvement should be the responsibility of society? Finally, since human irrationality was the consequence of false ideas, instilled by faulty schooling, should not education be a prime concern of rulers? To pose those questions is to anticipate the agenda of the Enlightenment.

The proto-Enlightenment. If Locke was the most influential philosopher in the swirling debates of fin de siècle Holland, the most prolific writer and educator was Pierre Bayle, whom Voltaire called "the first of the skeptical philosophers." He might also be called the first of the encyclopaedists, for he was more publicist than philosopher, eclectic in his interests, information, and ideas. The title *Nouvelles de la république des lettres* (1684–87) conveys the method and ideal of this superior form of journalism. Bayle's *Historical Dictionary* (1697) exposed the fallacies and deceits of the past by the plausible method of biographical articles. "The grounds of doubting are themselves doubtful; we must therefore doubt whether we ought to doubt." Lacking a sound criterion of truth or a system by which evidence could be tested but hating dogma and mistrusting authority, Bayle was concerned with the present state of knowledge. He may have been as much concerned with exposing the limitations of human reason as with attacking superstition. Translated and abridged, as, for example, by order of Frederick II of Prussia, the *Dictionary* became the skeptic's bible. The effect of Bayle's work and that of others less scrupulous, pouring from the presses of the Netherlands and Rhineland and easily penetrating French censorship, could not fail to be broadly subversive.

Bayle's seminal role in the cultural exchange of his time points to the importance of the Dutch Republic in the 17th century. Because Holland contributed little to science, philosophy, or even art at the time of the philosophes, though enviable enough in the tranquil lives of many of its citizens, its golden 17th century tends to be overlooked in traditional accounts of the Enlightenment. Wealth derived from trade, shipping, and finance and the toleration that attracted Sephardic Jews, Protestants from Flanders and France, and other refugees or simply those who sought a relatively open society combined to create a climate singularly favourable to enterprise and creativity. It was urban, centring on Amsterdam, and it was characterized by a rich artistic life created by painters who worked to please patrons who shared their values. It was pervaded by a scientific spirit. Pieter de Hooch's search for new ways of portraying light, Spinoza's pursuit of a rational system that would comprehend all spiritual truth. Antony van Leeuwenhoek's use of the microscope to reveal the hidden and minute, Hermann Boerhaave's dissection of the human corpse, Jan Blaeuw's accuracy in the making of maps or Huygens' in the new pendulum clock—each represents that passion for discovery that put 17th-century Holland in a central position between the Renaissance and the Enlightenment, with some of the creative traits of both periods. Its spirit is epitomized in the university of Leiden, which attracted students from throughout Europe by its excellence in medicine and law and its relative freedom from ecclesiastical authority.

It was fitting, therefore, that much of the writing that helped form the Enlightenment emanated from the printing presses of the Huguenot emigré Louis Elsevier at Amsterdam and Leiden. Bayle's skepticism belongs to

the time when dust was still rising from the collapsing structures of the past, obscuring such patterns of thought as would eventually emerge. There was no lack of material for them. Not only did learning flourish in the cultural common market that served the needs of those who led or followed intellectual fashions; also important, though harder to measure, was the influence of the new relativism, grounded in observable facts about an ever-widening world. It was corrosive alike of Cartesian method, classical regulation, and traditional theology. Of Descartes, Huygens had written that he had substituted for old ideas "causes for which one can comprehend all that there is in nature."

Allied to that confidence in the power of reason was a prejudice against knowledge that might distort argument. Blaise Pascal had perfectly exemplified that rationalist frame of mind prone to introspection, which in his case—that of mathematical genius and literary sensibility in rare combination—produced some of the finest writing of his day. But the author of the *Pensées* (1669) was reluctant to travel: "All the ills that affect a man proceed from one cause, namely that he has not learned to sit quietly and contentedly in one room." Again, the object of the protagonists of the prevailing classicism had been to establish rules: for language (the main role of the Académie), for painting (as in the work of Nicolas Poussin), even for the theatre, where Jean Racine's plays of heightened feeling and pure conflict of ideal or personality gain effect by being constrained within the framework of their Greek archetypes.

History and social thought. Order, purity, clarity: such were the classical ideals. They had dominated traditional theology as represented by its last great master, Jacques-Bénigne Bossuet. His *Politique tirée des propres paroles de l'Écriture sainte* ("Statecraft Drawn from the Very Words of the Holy Scriptures") and *Discours sur l'histoire universelle* offered a worldview and a history based on the Old Testament. Bossuet believed in the unity of knowledge as so many branches of Christian truth. His compelling logic and magisterial writing had a strong influence. When, however, the hypotheses were tested and found wanting, the very comprehensiveness of the system ensured that its collapse was complete. Bossuet had encouraged Richard Simon when he set out to refute Protestantism through historical study of the Bible but was shocked when he saw where it led. Inevitably, scholarship revealed inconsistencies and raised questions about the way that the Bible should be treated: if unreliable as history, then how sound was the basis for theology? Simon's works were banned in 1678, but Dutch printers ensured their circulation. No censorship could prevent the development of historical method, which was making a place for itself in the comprehensive search for truth. With Edward Gibbon (himself following the example of the 17th-century giants of church history), Jean Mabillon, and Louis Tillemont historians were to become more skilled and scrupulous in the use of evidence. The philosophes characteristically believed that history was becoming a science because it was subject to philosophical method. It also was subject to the prevailing materialist bias, which is why, scholarly though individual writers like David Hume might be, the Enlightenment was in some respects vulnerable to fresh insights about man—such as those of Étienne Bonnot de Condillac, who believed that human beings could be molded for their own good—and further research into the past—which, for Claude-Adrien Helvétius, was simply the worthless veneration of ancient laws and customs.

In 1703 Baron de Lahontan introduced the idea of the "noble savage," who led a moral life in the light of natural religion. In relative terms, the uniquely God-given character of European values was questioned; Louis XIV's persecution of the Huguenots and Jansenists offered an unappealing example. Philosophers were provided, through the device of *voyages imaginaires,* with new insights and standards of reference. As Archbishop Fénelon was to show in *Télémaque* (1699)—where the population of his imaginary republic of Salente was engaged in farming and the ruler, renouncing war, sought to increase the wealth of the kingdom—a utopian idyll could be a vehicle for criticism of contemporary institutions. A bishop and sentimental aristocrat, heir to the tradition of Christian agrarianism, might seem an unlikely figure to appear in the pantheon of the Enlightenment. But his readers encountered views about the obligations as well as rights of subjects that plainly anticipate its universalism, as in the *Dialogue des morts:* "Each individual owes incomparably more to the human race, the great fatherland, than to the country in which he is born."

The language of the Enlightenment. It is easier to identify intellectual trends than to define enlightened views, even where, as in France, there was a distinct and self-conscious movement, which had by mid-century the characteristics of a party. Clues can be found in the use commonly made of certain closely related cult words such as Reason, Nature, and Providence. From having a sharp, almost technical sense in the work of Descartes, Pascal, and Spinoza, reason came to mean something like common sense, along with strongly pejorative assumptions about things not reasonable. For Voltaire, the reasonable were those who believed in progress: he lived "in curious times and amid astonishing contrasts: reason on the one hand, the most absurd fanaticism on the other." Nature in the post-Newtonian world became a system of intelligible forces that grew as the complexity of matter was explored and the diversity of particular species discovered. It led to the pantheism of the Irish writer John Toland, for whom nature replaced God, and to the absolute doubt of Julien La Mettrie, who in *L'Homme machine* (1747) took the position that nothing about nature or its causes was known. In England, in the writing of Lord Shaftesbury and David Hartley, nature served the cause of sound morals and rational faith. One of the foremost theologians, Joseph Butler, author of the *Analogy of Religion* (1736), tested revelation against nature and in so doing erased the troublesome distinction in a manner wholly satisfying to those who looked for assurance that God could be active in the world without breaking the laws of its being. Finally, to Jean-Jacques Rousseau, nature—the word that had proved so useful to advocates of an undogmatic faith, of universal principles of law or even, in the hands of the physiocrats, the "natural," or market, economy—acquired a new resonance. In his *Discourse on the Origin of Inequality* (1755), he wrote: "We cannot desire or fear anything, except from the idea of it, or from the simple impulse of nature." Nature had become the primal condition of innocence in which man was whole—not perfect, but imbued with virtues that reflected the absence of restraints.

Along with the new view of the universe grew belief in the idea of a benign Providence, which could be trusted because it was visibly active in the world. Writers sought to express their sense of God's benevolent intention as manifest in creation. To the Abbé Pluche domestic animals were not merely docile but naturally loved humanity. Voltaire, equally implausibly, observed of mountain ranges that they were "a chain of high and continuous aqueducts which, by their apertures allow the rivers and arms of the sea the space which they need to irrigate the land." The idea of Providence could degenerate into the fatuous complacency that Voltaire himself was to deride and against which—in particular, the idea that the universe was just a vast theatre for the divine message—Samuel Taylor Coleridge was memorably to rebel. Faith, wrote the English poet, "could not be intellectually more evident without being morally less effective; without counteracting its own end by sacrificing the life of faith to the cold mechanism of a worthless because compulsory assent." So the Enlightenment can be seen to be carrying the seeds of its own disintegration. The providential idea was based on unscientific assumptions in an age in which scientists, favoured by a truce with men of religion, were free to pursue researches that revealed an untidier, therefore less comforting, world. Newton had argued, from such problems as irregularities in the orbit of planets, that divine intervention was necessary to keep the solar system operating regularly. D'Alembert found, however, that such problems were self-correcting. From being the divine mechanic had God now become the divine spectator?

No less unsettling were the findings of geologists. Jean-Étienne Guettard concluded that the evidence of fossils found in the volcanic hills of the Puy de Dôme in south-central France conflicted with the time scheme of the Old Testament. Whether, like the Count de Buffon, they attributed to matter a form of life, speculated about life as a constant, shapeless flux, or postulated a history of the world that had evolved over an immensely long time, scientists were dispensing with God as a necessary factor in their calculations. Some theologians sought compromise, while others retreated, looking to a separate world of intuitive understanding for the justification of faith. Joseph Butler pointed to conscience, the voice of God speaking to the human soul. He deplored the enthusiasm that characterized the tireless preaching of John Wesley and his message of the love of God manifested in Christ. "A true and living faith in God," Butler declared, "is inseparable from a sense of pardon from all past and freedom from all present sins." It was not the freedom understood by the philosophes, but it touched hearts and altered lives. Meanwhile the path of reason was open for the avowed atheism of Baron d'Holbach, who declared in his *Système de la nature* (1770; "The System of Nature") that there was no divine purpose: "The whole cannot have an object for outside itself there is nothing towards which it can tend." Another approach was taken by David Hume, author of *Treatise on Human Nature* (1739) and the *Dialogues Concerning Natural Religion* (1779). The notion of miracles was repugnant to reason, but he was content to leave religion as a mystery, to be a skeptic about skepticism, and to deny that man could reach objective knowledge of any kind.

These may appear to have been intellectual games for the few. It could only be a privileged, relatively leisured minority, even among the educated, who actively participated in debate or could even follow the reasoning. The impact was delayed; it was also uneven. In Dr. Johnson's England the independence bestowed by the Anglican clergyman's freehold and the willingness of the established church to countenance rational theology created a shock absorber in the form of the Broad Church. In Protestant countries criticism tended to be directed toward amending existing structures: there was a pious as well as an impious Enlightenment. Among Roman Catholic countries France's situation was in some ways unique. Even there orthodox doctrines remained entrenched in such institutions as the Sorbonne; some bishops might be worldly but others were conscientious; monasteries decayed but parish life was vital and curés (parish priests) well trained. Nor was theology neglected: in 1770, French publishers brought out 70 books in defense of the faith. Of course the philosophes, endowed with the talents and the means to mount sustained campaigns, ensured that the question of religion remained high on the agenda. There was also a ready sale for writers who sought to apply the rational and experimental methods to what Hume was to call the science of man.

Man and society. Chief among them was Charles de Secondat de Montesquieu. His presidency in the *parlement* of Bordeaux supported the career of a litterateur, scholarly but shrewd in judgment of men and issues. In the *Persian Letters* (1721), he had used the supposed correspondence of a Persian visitor to Paris to satirize both the church (under that "magician" the pope) and the society upon which it appeared to impose so fraudulently. His masterpiece, *The Spirit of Laws,* appeared in 22 editions within 18 months of publication in 1748. For this historically minded lawyer, laws were not abstract rules but were necessary relationships derived from nature. Accepting completely Locke's sensationalist psychology, he pursued the line of the Sicilian Giambattista Vico, the innovative author of *The New Science* (1725), toward the idea that human values are the evolving product of society itself. Among social factors, he listed climate, religion, laws, the principles of government, the example of the past, and social practices and manners and concluded that from these a general spirit is formed. Montesquieu's concern with knowledge as a factor in shaping society is characteristic of the Enlightenment. Nor was he alone in his Anglophile tendency, though it did not prevent him from misinterpreting the English constitution as being based on the separation of powers. The idea that moral freedom could be realized only in a regime whose laws were enacted by an elected legislature, administered by a separate executive, and enforced by an independent judiciary was to be more influential in the New World than in the Old. His theories reflected a Newtonian view of the static equilibrium of forces and were influenced by his perception of the French government as increasingly arbitrary and centralist; they were conceived as much as a safeguard against despotism as an instrument of progress.

Montesquieu's political conservatism belonged to a world different from that of the younger generation of philosophes, for whom the main obstacle to progress was privilege; they put their trust in "the enlightened autocrat" and in his mandate for social engineering. They might fear, like Claude Helvétius, that his theories would please the aristocracy. Helvétius—a financier, amateur philosopher, and author of the influential *De l'esprit* (1759; "On the Mind")—advocated enlightened self-interest in a way that found an echo in physiocratic economic theory and argued that each individual, in seeking his own good, contributed to the general good. Laws, being man-made, should be changed so as to be more useful. The spirit of the Enlightenment is well conveyed by his suggestion that experimental ethics should be constructed in the same way as experimental physics. By contrast, Montesquieu, whose special concern was the sanctity of human law, saw the problem of right conduct as one of adapting to circumstances. The function of reason was to bring about accord between human and natural law. While the objective nature of his inquiry encouraged those who trusted in the power of reason to solve human problems, it was left to those who saw the Enlightenment in more positive terms to work for change.

François-Marie Arouet, whose nom de plume Voltaire was to become almost synonymous with the Enlightenment, was a pupil of the Jesuits at their celebrated college of Louis-le-Grand; his political education included 11 months in the Bastille. The contrast between the arbitrary injustice epitomized by the lettre de cachet that brought about his imprisonment, without trial, for insulting a nobleman and the free society he subsequently enjoyed in England was to inspire a life's commitment to the principles of reason, liberty, justice, and toleration. Voltaire at times played the role of adviser to princes (notably Frederick II) but learned that it was easier to criticize than to change institutions and laws. Like other philosophes living under a regime that denied political opportunity, he was no politician. Nor was he truly a philosopher in the way that Locke, Hume, or even Montesquieu can be so described. His importance was primarily as an advocate at the bar of public opinion. The case for the reform of archaic laws and the war against superstition was presented with passion and authority, as notably in his *Philosophical Dictionary. Candide* (1759) shows his elegant command of language, whose potential for satire and argument had been demonstrated by Pascal's *Provincial Letters* of a century before. With astute judgment, he worked on the reader's sensibilities. "The most useful books," he wrote, "are those to which the readers themselves contribute half; they develop the idea of which the author has presented the seed." He could lift an episode—the execution of Admiral Byng (1757) for failing to win a battle; of Jean Calas, seemingly, for being a Huguenot (1762); or of the Chevalier de la Barre, after torture, for alleged blasphemy (1766)—to the level at which it exemplified the injustices committed when man would not listen to the voice of reason or could not do so because of archaic laws. In *Candide,* he presented the debate between the optimistic Dr. Pangloss and Martin, who believes in the reality of evil, in a way that highlights the issues and is as significant now as then.

Voltaire mounted his campaigns from a comfortable base, his large estate at Ferney. He was vain enough to relish his status as a literary lion and freedom's champion. He could be vindictive and was often impatient with differing views. In his reluctance to follow ideas through or

consider their practical implications and in his patrician disregard for the material concerns of ordinary people, he epitomized faults with which the philosophes can be charged, the more because they were so censorious of others. He was generous chiefly in imaginative energy, in the indignation expressed in the celebrated war cry "Écrasez l'infâme" (literally "crush infamy," signifying for Voltaire the intolerance of the church), and in the time he devoted to the causes of wronged individuals with whose plight he could identify. He had little to put in place of the religion he abused and offered no alternative vision. He did succeed notably in making people think about important questions—indeed, his questions were usually clearer than his answers.

The *Encyclopédie*. The Marquis de Condorcet, a mathematician and one of the more radical of his group, described his fellow philosophes as "a class of men less concerned with discovering truth than with propagating it." That was the spirit which animated the great *Encyclopédie,* the most ambitious publishing enterprise of the century. It appeared in 17 volumes between 1751 and 1765, after checks and delays that would have disheartened anyone less committed than its publisher, André-François le Breton, or its chief editor and presiding genius, Denis Diderot. Its publishing history is rich in incident and in what it reveals of the ambience of the Enlightenment. The critical point was reached in 1759, when French defeats made the authorities sensitive to anything that implied criticism of the regime. The publication of Helvétius' *De l'esprit,* together with doubts about the orthodoxy of another contributor, the Abbé de Prades, and concern about the growth of Freemasonry, convinced government ministers that they faced a plot to subvert authority. If they had been as united as the officials of the church, the *Encyclopédie* would have been throttled. It was placed on the Index of Forbidden Books, and a ban of excommunication was pronounced on any who should read it; but even Rome was equivocal. The knowledge that Pope Benedict XIV was privately sympathetic lessened the impact of the ban; Malesherbes, from 1750 to 1763 director of the Librairie, whose sanction was required for publication, eased the passage of volumes he was supposed to censor. Production continued, but without Rousseau, an early contributor, who became increasingly hostile to the encyclopaedists and their utilitarian philosophy.

Diderot's coeditor, the mathematician Jean le Rond d'Alembert, had, in his preface, presented history as the record of progress through learning. The title page proclaimed the authors' intention to outline the present state of knowledge about the sciences, arts, and crafts. Among its contributors were craftsmen who provided the details for the technical articles. Pervading all was Diderot's moral theme: through knowledge "our children, better instructed than we, may at the same time become more virtuous and happy." Such utilitarianism, closely related to Locke's environmentalism, was one aspect of what d'Alembert called "the philosophic spirit." If it had been only that, it would have been as useful as Ephraim Chambers' *Cyclopaedia* (1727), which it set out to emulate. Instead, it became the textbook for the thoughtful—predominantly officeholders, professionals, the bourgeoisie, and particularly the young, who might appreciate Diderot's idea of the *Encyclopédie* as the means by which to change the common way of thinking. In the cause, Diderot sustained imprisonment in the jail at Vincennes (1749) and had to endure the condemnation and burning of one of his books, *Philosophic Thoughts* (1746). There was nothing narrow about his secular mission. *Pensées sur l'interprétation de la nature* (1753) advanced the idea of nature as a creative process of which man was an integral part. But his greatest achievement was the *Encyclopédie.* Most of the important thinkers of the time contributed to it. Differences were to be expected, but there was enough unanimity in principles to endow the new gospel of scientific empiricism with the authority that Scripture was losing. It was also to provide a unique source for reformers. Catherine II of Russia wrote to the German critic Friedrich Melchior Grimm for suggestions as to a system of education for young people. Meanwhile, she said she would "flip through the *Encyclopédie;* I shall certainly find in it everything I should and should not do."

Rousseau and his followers. Diderot prefigured the unconventional style that found its archetype in Jean-Jacques Rousseau. In his novel of the 1760s, *Rameau's Nephew,* Diderot's eccentric hero persuades his bourgeois uncle, who professes virtue, to confess to actions so cynical as to be a complete reversal of accepted values. Rousseau was close to this stance when he ridiculed those who derived right action from right thinking. He understood the interests of the people, which the philosophes tended to neglect and which Thomas Paine considered in the *Rights of Man* (1791). If virtue were dependent on culture and culture the prerogative of a privileged minority, what was the prospect for the rest: "We have physicians, geometricians, chemists, astronomers, poets, musicians and painters in plenty; but no longer a citizen among us." Rousseau is thus of the Enlightenment yet against it, at least as represented by the mechanistic determinism of Condillac or the elitism of Diderot, who boasted that he wrote only for those to whom he could talk—*i.e.,* for philosophers. Rousseau challenged the privileged republic of letters, its premises, and its principles. His *Confessions* depicted a well-intentioned man forced to become a rogue and outcast by the artificiality of society. His first essay, *Discourse on the Arts and Sciences* (1750), suggested the contradiction between the exterior world of appearances and the inner world of feeling. With his view of culture now went emphasis on the value of emotions. Seminal use of concepts—such as "citizen" to indicate the rights proper to a member of a free society—strengthened signals that could otherwise confuse as much as inspire.

Dealing with the basic relations of life, Rousseau introduced the prophetic note that was to sound through democratic rhetoric. The state of nature was a hypothesis rather than an ideal: man must seek to recover wholeness at a higher level of existence. For this to be possible he must have a new kind of education and humanity a new political constitution. *Émile* (1762) proposed an education to foster natural growth. His *Social Contract* (1762) was banned, and this lent glamour to proposals for a constitution to enable the individual to develop without offending against the principle of social equality. The crucial question concerned legitimate authority. Rousseau rejected both natural law and force as its basis. He sought a form of association that would allow both security and the natural freedom in which "each man, giving himself to all, gives himself to nobody." It is realized in the form of the general will, expressed in laws to which all submit. More than the sum of individual wills, it is general in that it represents the public spirit seeking the common good, which Rousseau defined as liberty and equality, the latter because liberty cannot subsist without it. He advocated the total sovereignty of the state, a political formula which depended on the assumption that the state would be guided by the general will. Rousseau's good society was a democratic and egalitarian republic. Geneva, his birthplace, was to prove boundless in inspiration. Rousseau's influence may have been slight in his lifetime, though some were proud to be numbered among admirers. His eloquence touched men of sensibility on both sides of the Atlantic.

The French writer Morelly in the *Code de la nature* (1755), attacked property as the parent of crime and proposed that every man should contribute according to ability and receive according to need. Two decades later, another radical abbé, Gabriel de Mably, started with equality as the law of nature and argued that the introduction of property had destroyed the golden age of man. In England, William Godwin, following Holbach in obeisance to reason, condemned not only property but even the state of marriage: according to Godwin, man freed from the ties of custom and authority could devote himself to the pursuit of universal benevolence. To the young poets William Wordsworth and Percy Bysshe Shelley it was a beguiling vision; those less radical might fear for social consequences, such as the draftsmen of the Declaration of Rights of 1789, who were careful to proclaim the sacred right of property. Thomas Jefferson made the rights of man the foundation of his political philosophy as well as

of the U.S. Constitution, but he remained a slave owner. The idea of "de-natured" man was as potent for the unsettling of the ancien régime as loss of the sense of God had been for the generation of Luther and Ignatius. It struck home to the educated young who might identify with Rousseau's self-estrangement and read into the image of "man everywhere in chains" their own perception of the privilege that thwarted talent. Such were Maximilien Robespierre, the young lawyer of Arras; Aleksandr Radishchev, who advocated the emancipation of Russian serfs, or the Germans who felt restricted in regimented, often minuscule states. Both the severe rationalism of Kant and the idealism of Sturm und Drang found inspiration in Rousseau. Yet Kant's *Critique of Pure Reason* (1781) and the sentimental hero portrayed by Goethe in his *Sorrows of Young Werther* (1774) mark the end of the Enlightenment. "It came upon us so gray, so cimmerian, so corpse-like that we could hardly endure its ghost," wrote Goethe, speaking for the Romantic generation and pronouncing valediction.

In France the Enlightenment touched government circles only through individuals, such as Anne-Robert Turgot, a physiocrat, finance minister (1774–76), and frustrated reformer. The physiocrats, taking their cue from such writers as François Quesnay, author of *Tableau économique* (1758), advocated the removal of artificial obstacles to the growth of the natural economic order of a free market for the produce of the land. Even Adam Smith, who wrote the *Wealth of Nations* (1776) with a capitalist economy in mind, could see his avowed disciple William Pitt move only cautiously in the direction of free trade. Though the visionary William Blake could be adduced to show that there was powerful resistance to the new industrial society, the physician and scientist Erasmus Darwin was—with his fellow luminaries of the Lunar Society, Josiah Wedgwood and Matthew Boulton—at the heart of the entrepreneurial culture: there was no deep divide separating the English philosophes, with their sanctification of private property and individual interests, from the values and programs of government. In *dirigiste* France, where there was no internal common market and much to inhibit private investment, physiocratic ideas were politically naive: the gap between theory and implementation only illustrates the way in which the Enlightenment undermined confidence in the regime. Operating in a political vacuum, the philosophes could only hope that they would, like Diderot with Catherine the Great, exercise such influence abroad as might fulfill their sense of mission. In both Germany and Italy, however, circumstances favoured emphasis on the practical reforms that appealed as much to the rulers as to their advisers.

The Aufklärung. In Germany the Aufklärung found its highest expression in a science of government. One explanation lies in the importance of universities. There were nearly 50 by 1800 (24 founded since 1600); they were usually the product of a prince's need to have trained civil servants rather than of a patron's zeal for higher learning. Not all were as vigorous as Halle (1694) or Göttingen (1737), but others, such as Vienna in the last quarter of the 18th century, were inspired to emulate them. In general, the universities dominated intellectual and cultural life. Rulers valued them, and their teachers were influential, because they served the state by educating those who would serve. Leading academic figures held posts, enabling them to advise the government: the political economist Joseph von Sonnenfels was an adviser to the Habsburgs on the serf question. Lutheranism was another important factor in the evolution of the attitude to authority that makes the German Enlightenment so markedly different from the French. In the 18th century it was further influenced by Pietism, which was essentially a devotional movement though imbued with a reforming spirit. Nor was the earnest religious spirit confined to the Protestant confessions. In Maria Theresa's Austria, Jansenism, which penetrated Viennese circles from Austrian Flanders, was as important in influencing reforms in church and education as it was in sharpening disputes with the Papacy. But there was nothing comparable, even in the Catholic south and Rhineland, to the revolt of western intellectuals against traditional dogma. Amid all his speculations, Leibniz, who more than any other influenced German thought, had held to the idea of a personal God not subject to the limitations of a material universe. It was devotion, not indifference, that made him, with Bossuet, seek ground for Christian reunion.

Leibniz's disciple, Christian Wolff, a leading figure of the Aufklärung, was opposed to the Pietists, who secured his expulsion from Halle in 1723. Yet, though he believed that reason and revelation could be reconciled, he shared with the Pietists fundamental Christian tenets. In Halle there emerged a synthesis of Wolffism and Pietism, a scientific theology that was progressive but orthodox. Pervading all was respect for the ruler, reflecting the acceptance of the *cuius regio, eius religio* principle; it reduced the scope for internal conflicts, which elsewhere bred doubts about authority. In translating conservative attitudes into political doctrines, the contribution of the lawyers and the nature of the law they taught were crucial. In place of the moral vacuum in which the single reality was the power of the individual ruler, there had come into being a body of law, articulated preeminently by Hugo Grotius in *On the Law of War and Peace.* It was grounded not only in proven principles of private law but also in the Christian spirit, though it was strengthened by Grotius' separation of natural law from its religious aspects. As expounded by Wolff and the historiographer Samuel Pufendorf, natural law endorsed absolutism. They did not wholly neglect civil rights, they advocated religious toleration, and they opposed torture, but, living in a world far removed from that of Locke or Montesquieu, they saw no need to stipulate constitutional safeguards. Wolff declared that "he who exercises the civil power has the right to establish everything that appears to him to serve the public good." Such a sovereign, comprising legislative, executive, and judicial functions, was also, as defined in Wolff's *Rational Thoughts on the Social Life of Mankind* (1756), a positive force, benevolent: he was Luther's "godly prince" in 18th-century dress, serving his people's needs. *Cameralwissenschaft*—the science and practice of administration—would serve the ruler by increasing the revenue and also improve the lot of the people.

Envisaging progress under the sovereign who created the schools, hospitals, and orphanages and provided officials to run them, Wolff was only one among numerous writers who contributed to the ideal of benevolent bureaucratic absolutism, or *Wohlfahrstaat.* Though also influenced by the local school of cameralists and 17th-century writers such as Philippe Wilhelm von Hörnigk and Johann Joachim Becher, the emperor Joseph II, having the largest area to rule and the most earnest commitment to its principles, came to exemplify the Aufklärung. By his time, however, there was a growing reaction against the soulless rationality of the natural lawyers. With the exception of the Prussian critic Johann Gottfried Herder, whose ideal *Volk*-state would have a republican constitution, political thought was unaffected by the emphasis of the literary giants of Romanticism on freedom and spontaneity. His contemporary Kant, an anticameralist, believed in a degree of popular participation but would not allow even the theoretical right of revolution. In *Was ist Aufklärung?* Kant drew a vital distinction between the public and private use of one's reason. With Frederick the Great in mind, he advanced the paradox that can be taken as a text for the Enlightenment as well as for German history. The ruler with a well-disciplined and large army could provide more liberty than a republic.

> A high degree of civil freedom seems advantageous to a people's intellectual freedom, yet also sets up insuperable barriers to it. Conversely, a lesser degree of civil freedom gives intellectual freedom enough room to expand to its fullest extent.

The Enlightenment throughout Europe. Foreigners who came to see the monuments of Italy, or perhaps to listen to the music that they might recognize as the inspiration of some of the best of their own, were likely to return convinced that the country was backward. Its intellectual life might remain a closed book. As elsewhere, the Enlightenment consisted of small, isolated groups; measured by impact on governments, they had little obvious

effect. Where there was important change, it was usually the work of a ruler, such as Leopold of Tuscany, or a minister, such as Bernardo Tanucci in Naples. The power of the church, symbolized by the listing of Galileo, a century after his condemnation, on the Index of Forbidden Books; the survival, particularly in the south, of an oppressive feudal power; and the restrictive power of the guilds were among the targets for liberals and humanitarians. Universities like Bologna, Padua, and Naples had preserved traditions of scholarship and still provided a stimulating base for such original thinkers as Giambattista Vico and Antonio Genovesi, a devout priest, professor of philosophy, and pioneer in ethical studies and economic theory. The distinctive feature of the Italian Enlightenment, however, as befitted the country that produced such scientists as Luigi Galvani and Alessandro Volta, was its practical tendency—as if speculation were a luxury amid so much disorder and poverty. Its proponents introduced to political philosophy utilitarianism's slogan "the greatest happiness of the greatest number." They also felt the passion of patriots seeking to rouse their countrymen. The greatest representative of the Italian Enlightenment was Cesare Beccaria, whose work included *Of Crimes and Punishments* (1764); in his lifetime it was translated into 22 languages. His pupils and imitators included Catherine II of Russia and Jeremy Bentham, the most influential figure in the long-delayed reform of English law. "Newtoncino," as Beccaria was called by admirers, claimed to apply the geometric spirit to the study of criminal law. There was indeed no mystique about his idea of justice. "That bond which is necessary to keep the interest of individuals united, without which men would return to their original state of barbarity," may recall the pessimism of Hobbes, but his formula for penalties answered to the enlightened ruler's search for what was both rational and practical: "Punishments which exceed the necessity of preserving this bond are in their nature unjust." So Beccaria condemned torture and capital punishment, questioned the treatment of sins as crimes, and stressed the value of equality before the law and of prevention having priority over punishment. Much of the best enlightened thought comes together in Beccaria's work, in which the link between philosophy and reform is clearly evident.

The Enlightenment was a European phenomenon: examples of enlightened thought and writing can be found in every country. There were important reforms in late 18th-century Spain under the benevolent rule of Charles III. There was little originality, however, about the *Luces* and its disciples. The spirit of acceptance was stronger than that of inquiry; Spain apparently was a casebook example of the philosophes' belief that religion stifled freedom of thought. It was a priest, Benito Feijóo y Montenegro, who did as much as any man to prepare for the Spanish Enlightenment, preaching the criterion of social utility in a society still obsessed with honour and display. Conservatism was, however, well entrenched, whether expressed in the pedantic procedures of the Inquisition or in the crude mob destroying the Marqués de Squillace's new street lamps in Madrid in 1766. "It is an old habit in Spain," wrote the Count de Campomanes, "to condemn everything that is new."

So the accent in Spain was utilitarian—more *Colbertiste* than *philosophe*—as in other countries where local circumstances and needs dictated certain courses of action. Johann Struensee's liberal reforms in Denmark (1771–72) represented, besides his own eccentricity, justifiable resentment at an oppressive Pietist regime. The constitutional changes that followed the first partition of Poland in 1772 were dictated as much by the need to survive as by the imaginative idealism of King Stanislaw. Despite her interest in abstract ideals, reforms in law and government in Catherine the Great's vast Russian lands represented the overriding imperative, the security of the state. In Portugal, Pombal, the rebuilder of post-earthquake Lisbon, was motivated chiefly by the need to restore vitality to a country with a pioneering maritime past. Leopold of Tuscany was able to draw on a rich humanist tradition and civic pride. Everywhere the preferences of the ruler had an idiosyncratic effect, as in the Margrave Charles Frederick of Baden's unsuccessful attempt in 1770 to introduce a land tax (the *impôt unique* advocated by the physiocrats), or in Pombal's campaign to expel the Jesuits (copied supinely by other Catholic rulers).

Overall it may seem as easy to define the Enlightenment by what it opposed as by what it advocated. Along with some superficiality in thought and cynical expediency in action, this is the basis for conservative criticism: When reason is little more than common sense and utilitarianism so infects attitudes that progress can be measured only by material standards, then Edmund Burke's lament about the age of "sophisters, economists, and calculators" is held to be justified. Some historians have followed Burke in ascribing not only Jacobin authoritarianism but even 20th-century totalitarianism to tendencies within the Enlightenment. Indeed, it may be that the movement that helped to free man from the past and its "self-incurred tutelage" (Kant) failed to prevent the development of new systems and techniques of tyranny. This intellectual odyssey, following Shaftesbury's "mighty light which spreads itself over the world," should, however, be seen to be related to the growth of the state, the advance of science, and the subsequent development of an industrial society. For their ill effects, the Enlightenment cannot be held to be mainly responsible. Rather it should be viewed as an integral part of a broader historical process. In this light it is easier to appraise the achievements that are its singular glory. To be challenged to think harder, with greater chance of discovering truth; to be able to write, speak, and worship freely; and to experience equality under the law and relatively humane treatment if one offended against it was to be able to live a fuller life. (G.R.R.T.)

Revolution and the growth of industrial society, 1789–1914

Developments in 19th-century Europe are bounded by two great events. The French Revolution broke out in 1789, and its effects reverberated throughout much of Europe for many decades. World War I began in 1914. Its inception resulted from many trends in European society, culture, and diplomacy during the late 19th century. In between these boundaries—the one opening a new set of trends, the other bringing long-standing tensions to a head—much of modern Europe was defined.

Europe during this 125-year span was both united and deeply divided. A number of basic cultural trends, including new literary styles and the spread of science, ran through the entire continent. European states were increasingly locked in diplomatic interaction, culminating in continentwide alliance systems after 1871. At the same time, this was a century of growing nationalism, in which individual states jealously protected their identities and indeed established more rigorous border controls than ever before. Finally, the European continent was to an extent divided between two zones of differential development. Changes such as the Industrial Revolution and political liberalization spread first and fastest in western Europe—Britain, France, the Low Countries, Scandinavia, and, to an extent, Germany and Italy. Eastern and southern Europe, more rural at the outset of the period, changed more slowly and in somewhat different ways.

Europe witnessed important common patterns and increasing interconnections, but these developments must be assessed in terms of nation-state divisions and, even more, of larger regional differences. Some trends, including the ongoing impact of the French Revolution, ran through virtually the entire 19th century. Other characteristics, however, had a shorter life span.

Some historians prefer to divide 19th-century history into relatively small chunks. Thus 1789–1815 is defined by the French Revolution and Napoleon; 1815–48 forms a period of reaction and adjustment; 1848–71 is dominated by a new round of revolution and the unifications of the German and Italian nations; and 1871–1914, an age of imperialism, is shaped by new kinds of political debate and the pressures that culminated in war. Overriding these important markers, however, a simpler division can also be useful. Between 1789 and 1849 Europe dealt

with the forces of political revolution and the first impact of the Industrial Revolution. Between 1849 and 1914 a fuller industrial society emerged, including new forms of states and of diplomatic and military alignments. The mid-19th century, in either formulation, looms as a particularly important point of transition within the extended 19th century.

THE INDUSTRIAL REVOLUTION

Economic effects. Undergirding the development of modern Europe between the 1780s and 1849 was an unprecedented economic transformation that embraced the first stages of the great Industrial Revolution and a still more general expansion of commercial activity. Articulate Europeans were initially more impressed by the screaming political news generated by the French Revolution and ensuing Napoleonic Wars, but in retrospect the economic upheaval, which related in any event to political and diplomatic trends, has proved more fundamental.

Effect of population growth

Major economic change was spurred by western Europe's tremendous population growth during the late 18th century, extending well into the 19th century itself. Between 1750 and 1800, the populations of major countries increased between 50 and 100 percent, chiefly as a result of the use of new food crops (such as the potato) and a temporary decline in epidemic disease. Population growth of this magnitude compelled change. Peasant and artisanal children found their paths to inheritance blocked by sheer numbers and thus had to seek new forms of paying labour. Families of businessmen and landlords also had to innovate to take care of unexpectedly large surviving broods. These pressures occurred in a society already attuned to market transactions, possessed of an active merchant class, and blessed with considerable capital and access to overseas markets as a result of existing dominance in world trade.

Heightened commercialization showed in a number of areas. Vigorous peasants increased their landholdings, often at the expense of their less fortunate neighbours, who swelled the growing ranks of the near-propertyless. These peasants, in turn, produced food for sale in growing urban markets. Domestic manufacturing soared, as hundreds of thousands of rural producers worked full- or part-time to make thread and cloth, nails and tools under the sponsorship of urban merchants. Craft work in the cities began to shift toward production for distant markets, which encouraged artisan-owners to treat their journeymen less as fellow workers and more as wage labourers. Europe's social structure changed toward a basic division, both rural and urban, between owners and nonowners. Production expanded, leading by the end of the 18th century to a first wave of consumerism as rural wage earners began to purchase new kinds of commercially produced clothing, while urban middle-class families began to indulge in new tastes, such as uplifting books and educational toys for children.

In this context an outright industrial revolution took shape, led by Britain, which retained leadership in industrialization well past the middle of the 19th century. In 1840, British steam engines were generating 620,000 horsepower out of a European total of 860,000. Nevertheless, though delayed by the chaos of the French Revolution and Napoleonic Wars, many western European nations soon followed suit; thus by 1860 British steam-generated horsepower made up less than half the European total, with France, Germany, and Belgium gaining ground rapidly. Governments and private entrepreneurs worked hard to imitate British technologies after 1820, by which time an intense industrial revolution was taking shape in many parts of western Europe, particularly in coal-rich regions such as Belgium, northern France, and the Ruhr area of Germany. German pig iron production, a mere 40,000 tons in 1825, soared to 150,000 tons a decade later and reached 250,000 tons by the early 1850s. French coal and iron output doubled in the same span—huge changes in national capacities and the material bases of life.

Changes in transportation

Technological change soon spilled over from manufacturing into other areas. Increased production heightened demands on the transportation system to move raw materials and finished products. Massive road and canal building programs were one response, but steam engines also were directly applied as a result of inventions in Britain and the United States. Steam shipping plied major waterways soon after 1800 and by the 1840s spread to oceanic transport. Railroad systems, first developed to haul coal from mines, were developed for intercity transport during the 1820s: the first commercial line opened between Liverpool and Manchester in 1830. During the 1830s local rail networks fanned out in most western European countries, and national systems were planned in the following decade, to be completed by about 1870. In communication, the invention of the telegraph allowed faster exchange of news and commercial information than ever before.

New organization of business and labour was intimately linked to the new technologies. Workers in the industrialized sectors laboured in factories rather than in scattered shops or homes. Steam and water power required a concentration of labour close to the power source. Concentration of labour also allowed new discipline and specialization, which increased productivity.

The new machinery was expensive, and businessmen setting up even modest factories had to accumulate substantial capital through partnerships, loans from banks, or joint-stock ventures. While relatively small firms still predominated, and managerial bureaucracies were limited save in a few heavy industrial giants, a tendency toward expansion of the business unit was already noteworthy. Commerce was affected in similar ways, for new forms had to be devised to dispose of growing levels of production. Small shops replaced itinerant peddlers in villages and small towns. In Paris, the department store, introduced in the 1830s, ushered in an age of big business in the trading sector.

Urbanization was a vital result of growing commercialization and new industrial technology. Factory centres such as Manchester grew from villages into cities of hundreds of thousands in a few short decades. The percentage of the total population located in cities expanded steadily, and big cities tended to displace more scattered centres in western Europe's urban map. Rapid city growth produced new hardships, for housing stock and sanitary facilities could not keep pace, though innovation responded, if slowly. Gas lighting improved street conditions in the better neighbourhoods from the 1830s onward, and sanitary reformers pressed for underground sewage systems at about this time. For the better-off, rapid suburban growth allowed some escape from the worst urban miseries.

Rural life changed less dramatically. A full-scale technological revolution in the countryside occurred only after the 1850s. Nevertheless, factory-made tools spread widely even before this time, as scythes replaced sickles for harvesting, allowing a substantial improvement in productivity. Larger estates, particularly in commercially minded Britain, began to introduce newer equipment, such as seed drills for planting. Crop rotation, involving the use of nitrogen-fixing plants, displaced the age-old practice of leaving some land fallow, while better seeds and livestock and, from the 1830s, chemical fertilizers improved yields as well. Rising agricultural production and market specialization were central to the growth of cities and factories.

The speed of western Europe's Industrial Revolution should not be exaggerated. By 1850 in Britain, far and away the leader still, only half the total population lived in cities, and there were as many urban craft producers as there were factory hands. Relatively traditional economic sectors, in other words, did not disappear and even expanded in response to new needs for housing construction or food production. Nevertheless, the new economic sectors grew most rapidly, and even other branches displayed important new features as part of the general process of commercialization.

Geographic disparities

Geographic disparities complicate the picture as well. Belgium and, from the 1840s, many of the German states were well launched on an industrial revolution that brought them steadily closer to British levels. France, poorer in coal, concentrated somewhat more on increasing production in craft sectors, converting furniture making, for example, from an artistic endeavour to standardized

output in advance of outright factory forms. Scandinavia and The Netherlands joined the industrial parade seriously only after 1850.

Southern and eastern Europe, while importing a few model factories and setting up some local rail lines, generally operated in a different economic orbit. City growth and technological change were both modest until much later in the 19th century, save in pockets of northern Italy and northern Spain. In eastern areas, western Europe's industrialization had its greatest impact in encouraging growing conversion to market agriculture, as Russia, Poland, and Hungary responded to grain import needs, particularly in the British Isles. As in eastern Prussia, the temptation was to impose new obligations on peasant serfs labouring on large estates, increasing the work requirements in order to meet export possibilities without fundamental technical change and without challenging the hold of the landlord class.

Social upheaval. In western Europe, economic change produced massive social consequences during the first half of the 19th century. Basic aspects of daily life changed, and work was increasingly redefined. The intensity of change varied, of course—with factory workers affected most keenly, labourers on the land least—but some of the pressures were widespread.

Working conditions

For wage labourers, the autonomy of work declined; more people worked under the daily direction of others. Early textile and metallurgical factories set shop rules, which urged workers to be on time, to stay at their machines rather than wandering around, and to avoid idle singing or chatter (difficult in any event given the noise of the equipment). These rules were increasingly enforced by foremen, who mediated between owners and ordinary labourers. Work speeded up. Machines set the pace, and workers were supposed to keep up: one French factory owner, who each week decorated the most productive machine (not its operators) with a garland of flowers, suggested where the priorities lay. Work, in other words, was to be fast, coordinated, and intense, without the admixture of distractions common in preindustrial labour. Some of these pressures spilled over to nonfactory settings as well, as craft directors tried to urge a higher productivity on journeymen artisans. Duration of work everywhere remained long, up to 14 hours a day, which was traditional but could be oppressive when work was more intense and walking time had to be added to reach the factories in the first place. Women and children were widely used for the less skilled operations; again, this was no novelty, but it was newly troubling now that work was located outside the home and was often more dangerous, given the hazards of unprotected machinery.

The nature of work shifted in the propertied classes as well. Middle-class people, not only factory owners but also merchants and professionals, began to trumpet a new work ethic. According to this ethic, work was the basic human good. He who worked was meritorious and should prosper, he who suffered did so because he did not work. Idleness and frivolity were officially frowned upon. Middle-class stories, for children and adults alike, were filled with uplifting tales of poor people who, by dint of assiduous work, managed to better themselves. In Britain, Samuel Smiles authored this kind of mobility literature, which was widely popular between the 1830s and 1860s. Between 1780 and 1840, Prussian school reading shifted increasingly toward praise of hard work as a means of social improvement, with corresponding scorn for laziness.

Shifts in work context had important implications for leisure. Businessmen who internalized the new work ethic felt literally uncomfortable when not on the job. Overall, the European middle class strove to redefine leisure tastes toward personal improvement and family cohesion; recreation that did not conduce to these ends was dubious. Family reading was a common pastime. Daughters were encouraged to learn piano playing, for music could draw the family together and demonstrate the refinement of its women. Through piano teaching, in turn, a new class of professional musicians began to emerge in the large cities. Middle-class people, newly wealthy, were willing to join in sponsorship of certain cultural events outside the home, such as symphony concerts. Book buying and newspaper reading also were supported, with a tendency to favour serious newspapers that focused on political and economic issues and books that had a certain classic status. Middle-class people also attended informative public lectures and night courses that might develop new work skills in such areas as applied science or management.

Middle-class pressures by no means totally reshaped popular urban leisure habits. Workers had limited time and means for play, but many absented themselves from the factories when they could afford to (often preferring free time over higher earnings, to the despair of their managers). The sheer intensity of work constrained leisure nevertheless. Furthermore, city administrations tried to limit other traditional popular amusements, ranging from gambling to animal contests (bear-baiting, cockfighting) to popular festivals. Leisure of this sort was viewed as unproductive, crude, and—insofar as it massed urban crowds—dangerous to political order. Urban police forces, created during the 1820s in cities like London to provide more professional control over crime and public behaviour, spent much of their time combating popular leisure impulses during the middle decades of the 19th century. Popular habits did not fully accommodate to middle-class standards. Drinking, though disapproved of by middle-class critics, was an important recreational outlet, bringing men together in a semblance of community structure. Bars sprouted throughout working-class sections of town. On the whole, however, the early decades of the Industrial Revolution saw a massive decline of popular leisure traditions; even in the countryside, festivals were diluted by importing paid entertainers from the cities. Leisure did not disappear, but it was increasingly reshaped toward respectable family pastimes or spectatorship at inexpensive concerts or circuses, where large numbers of people paid professional entertainers to take their minds away from the everyday routine.

The growth of cities and industry had a vital impact on family life. The family declined as a production unit as work moved away from home settings. This was true not only for workers but also for middle-class people. Many businessmen setting up a new store or factory in the 1820s initially assumed that their wives would assist them, in the time-honoured fashion in which all family members were expected to pitch in. After the first generation, however, this impulse faded, in part because fashionable homes were located at some distance from commercial sections and needed separate attention. In general, most urban groups tended to respond to the separation of home and work by redefining gender roles, so that married men became the family breadwinners (aided, in the working class, by older children) and women were the domestic specialists.

The role of women

In the typical working-class family, women were expected to work from their early teens through marriage a decade or so later. The majority of women workers in the cities went into domestic service in middle-class households, but an important minority laboured in factories; another minority became prostitutes. Some women continued working outside the home after marriage, but most pulled back to tasks, such as laundering, that could be done domestically. Their other activities concentrated on shopping for the family (an arduous task on limited budgets), caring for children, and maintaining contacts with other relatives who might support the family socially and provide aid during economic hardships.

Few middle-class women worked in paid employment at any point in their lives. Managing a middle-class household was complex, even with a servant present. Standards of child rearing urged increased maternal attention, and women were also supposed to provide a graceful and comfortable tone for family life. Middle-class ideals held the family to be a sacred place and women its chief agents because of their innate morality and domestic devotion. Men owed the family good manners and the provision of economic security, but their daily interactions became increasingly peripheral. Many middle-class families also began, in the early 19th century, to limit their birth rate, mainly through increasing sexual abstinence. Having too many children could complicate the family's economic

well-being and prevent the necessary attention and support for the children who were desired. The middle class thus pioneered a new definition of family size that would ultimately become more widespread in European society.

New family arrangements, both for workers and for middle-class people, suggested new courtship patterns. As wage earners having no access to property, urban workers were increasingly able to form liaisons early in life without waiting for inheritance and without close supervision by a watchful community. Sexual activity began earlier in life than had been standard before the 1780s. Marriage did not necessarily follow, for many workers moved from job to job and some unquestionably exploited female partners who were eager for more durable arrangements. Rates of illegitimate births began to rise rapidly throughout western Europe from about 1780 (from 2 to 4 up to 10 percent of total births) among young rural as well as urban workers. Sexual pleasure, or its quest, became more important for young adults. Similar symptoms developed among some middle-class men, who exploited female servants or the growing numbers of brothels that dotted the large cities and that often did exceptional business during school holidays. Respectable young middle-class women held back from these trends. They were, however, increasingly drawn to beliefs in a romantic marriage, which became part of the new family ideal. Marriage age for middle-class women also dropped, creating an age disparity between men and women in the families of this class. Economic criteria for family formation remained important in many social sectors, but young people enjoyed more freedom in courtship, and other factors, sexual or emotional or both, gained increasing legitimacy.

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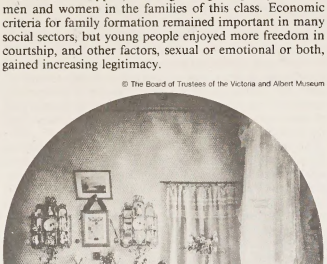

Photograph of a middle-class Victorian woman in her drawing room, 1865. In the Victoria and Albert Museum, London.

Changes in family life, rooted in shifts in modes of livelihood and methods of work, had substantial impact on all family members. Older people gained new roles, particularly in working-class families, where they helped out as baby-sitters for grandchildren. Women's economic power in the family decreased. Many groups of men argued vigorously that women should stick to family concerns. By the 1830s and '40s one result was the inception of laws that regulated women's hours of work (while leaving men free from protection or constraints); this was a humanitarian move to protect women's family roles, but it also reduced women's economic opportunities on grounds of their special frailty. The position of children also began to be redefined. Middle-class ideals held that children were innocents, to be educated and nurtured. Most working-class families urged a more traditional view of children as contributors to the family economy, but they too could see advantages in sending their children to school where possible and restricting their work in dangerous factories. Again, after the first decades of industrialization, reform laws began to respond. Legislation in Britain, France, and Prussia during the 1830s restricted the employment of young children in the factories and encouraged school attendance.

Along with its impact on daily patterns of life and family institutions, economic change began to shift Europe's social structure and create new antagonisms among urban social classes. The key division lay between the members of the middle class, who owned businesses or acquired professional education, and those of the working class, who depended on the sale of labour for a wage. Neither group was homogeneous. Many middle-class people criticized the profit-seeking behaviour of the new factory owners. Artisans often shunned factory workers and drew distinctions based on their traditional prestige and (usually) greater literacy. Some skilled workers, earning good wages, emulated middle-class people, seeking education and acquiring domestic trappings such as pianos.

Class antagonism

Nevertheless, the social divide was considerable. It increasingly affected residential patterns, as wealthier classes moved away from the crowded slums of the poor, in contrast to the greater mixture in the quarters of preindustrial cities. Middle-class people deplored the work and sexual habits of many workers, arguing that their bad behaviour was the root cause of poverty. City governments enacted harsh measures against beggars, while new national laws attempted to make charity harder to obtain. The British Poor Law Reform of 1834, in particular, tightened the limits on relief in hopes of forcing able-bodied workers to fend for themselves.

Class divisions manifested themselves in protest movements. Middle-class people joined political protests hoping to win new rights against aristocratic monopoly. Workers increasingly organized on their own despite the fact that new laws banned craft organizations and outlawed unions and strikes. Some workers attacked the reliance on machinery in the name of older, more humane traditions of work. Luddite protests of this sort began in Britain during the decade 1810–20. More numerous were groups of craft workers, and some factory hands, who formed incipient trade unions to demand better conditions as well as to provide mutual aid in cases of sickness or other setbacks. National union movements arose in Britain during the 1820s, though they ultimately failed. Huge strikes in the silk industry around Lyon, Fr., in 1831 and 1834 sought a living minimum wage for all workers. The most ambitious worker movements tended to emphasize a desire to turn back the clock to older work systems where there was greater equality and a greater commitment to craft skill, but most failed. Smaller, local unions did achieve some success in preserving the conditions of the traditional systems. Social protest was largely intermittent because many workers were too poor or too disoriented to mount a larger effort, but it clearly signaled important tensions in the new economic order.

THE AGE OF REVOLUTION

During the decades of economic and social transformation, western Europe also experienced massive political change. The central event throughout much of the Continent was the French Revolution (1789–99) and its aftermath. This was followed by a concerted effort at political reaction and a renewed series of revolutions from 1820 through 1848.

Connections between political change and socioeconomic upheaval were real but complex. Economic grievances associated with early industrialization fed into later revolutions, particularly the outbursts in 1848, but the newest social classes were not prime bearers of the revolutionary message. Revolutions also resulted from new political ideas directed against the institutions and social arrangements of the preindustrial order. Their results facilitated further economic change, but this was not necessarily their intent. Political unrest must be seen as a discrete factor shaping a new Europe along with fundamental economic forces.

Enlightenment sources of the French Revolution

The French Revolution. Revolution exploded in France in the summer of 1789, after many decades of ideological ferment, political decline, and social unrest. Ideologically, thinkers of the Enlightenment urged that governments

should promote the greatest good of all people, not the narrow interests of a particular elite. They were hostile to the political power of the Roman Catholic church as well as to the tax exemptions and landed power of the aristocracy. Their remedies were diverse, ranging from outright democracy to a more efficient monarchy, but they joined in insisting on greater religious and cultural freedom, some kind of parliamentary institution, and greater equality under the law. Enlightenment writings were widely disseminated, reaching many urban groups in France and elsewhere. The monarchy was in bad shape even aside from new attacks. Its finances were severely pressed, particularly after the wars of the mid-18th century and French involvement against Britain during the American Revolution. Efforts to reform the tax structure foundered against the opposition of the aristocracy. Finally, various groups in France were pressed by economic and social change. Aristocrats wanted new political rights against royal power. Middle-class people sought a political voice to match their commercial importance and a government more friendly to their interests. The peasant majority, pressed by population growth, sought access to the lands of the aristocracy and the church, an end to remaining manorial dues and services, and relief from taxation.

These various discontents came to a head when King Louis XVI called the Estates-General in 1789 to consider new taxes. This body had not met since 1614, and its calling released all the pressures building during recent decades, exacerbated by economic hardships resulting from bad harvests in 1787–88. Reform leaders, joined by some aristocrats and clergy, insisted that the Third Estate, representing elements of the urban middle class, be granted double the membership of the church and aristocratic estates and that the entire body of Estates-General vote as a unit—they insisted, in other words, on a new kind of parliament. The king yielded, and the new National Assembly began to plan a constitution. Riots in the summer of 1789 included a symbolic attack on the Bastille, a royal prison, and a series of risings in the countryside that forced repeal of the remnants of manorialism and a proclamation of equality under the laws. A Declaration of the Rights of Man and the Citizen trumpeted religious freedom and liberty of press and assembly, while reaffirming property rights. Church lands were seized, however, creating a rift between revolutionary and Roman Catholic sentiment. Guilds were outlawed (in 1791), as the revolution promoted middle-class beliefs in individual initiative and freedom for technological change. A 1791 constitution retained the monarchy but created a strong parliament, elected by about half of France's adult males—those with property.

This liberal phase of the French Revolution was followed, between 1792 and 1794, by a more radical period. Economic conditions deteriorated, prompting new urban riots. Roman Catholic and other groups rose in opposition to the revolution, resulting in forceful suppression and a corresponding growing insistence on loyalty to revolutionary principles. Monarchs in neighbouring countries—notably Britain, Austria, and Prussia—challenged the revolution and threatened invasion, which added foreign war to the unstable mix by 1792. Radical leaders, under the banners of the Jacobin party, took over the government, proclaiming a republic and executing the king and many other leaders of the old regime. Governmental centralization increased; the decimal system was introduced. Mass military conscription was organized for the first time in European history, with the argument that, now that the government belonged to the people, the people must serve it loyally. A new constitution proclaimed universal manhood suffrage, and reforms in education and other areas were widely discussed. The radical phase of the revolution brought increasing military success to revolutionary troops in effectively reorganized armies, which conquered parts of the Low Countries and Germany and carried revolutionary laws in their wake. The revolution was beginning to become a European phenomenon.

Jacobin radicalization

Jacobin rule was replaced by a more moderate consolidation after 1795, during which, however, military expansion continued in several directions, notably in parts of Italy. The needs of war, along with recurrent domestic unrest, prompted a final revolutionary regime change, in 1799, that brought General Napoleon Bonaparte to power.

The Napoleonic era. Napoleon ruled for 15 years, closing out the quarter-century so dominated by the French Revolution. His own ambitions were to establish a solid dynasty within France and to create a French-dominated empire in Europe. To this end he moved steadily to consolidate his personal power, proclaiming himself emperor and sketching a new aristocracy. He was almost constantly at war, with Britain his most dogged opponent but Prussia and Austria also joining successive coalitions. Until 1812, his campaigns were usually successful, as he was a master strategist, particularly in the rapid deployment of masses of troops and mobile field artillery. Napoleonic France directly annexed territories in the Low Countries and western Germany, applying revolutionary legislation in full. Satellite kingdoms were set up in other parts of Germany and Italy, in Spain, and in Poland. Only after 1810 did Napoleon clearly overreach himself. His empire stirred enmity widely, and in conquered Spain an important guerrilla movement harassed his forces. Russia, briefly allied, turned hostile, and an 1812 invasion attempt failed miserably in the cold Russian winter. A new alliance formed among the other great powers in 1813. France fell to the invading forces of this coalition in 1814, and Napoleon was exiled. He returned dramatically, only to be defeated at Waterloo in 1815; his reign had finally ended.

Napoleon's regime produced three major accomplishments, aside from its many military episodes. First, it confirmed many revolutionary changes within France itself. Napoleon was a dictator, maintaining only a sham parliament and rigorously policing press and assembly. Though some key liberal principles were in fact ignored, equality under the law was for the most part enhanced through Napoleon's sweeping new law codes; hereditary privileges among adult males became a thing of the past. A strongly centralized government recruited bureaucrats according to their abilities. New educational institutions, under state control, provided access to bureaucratic and specialized technical training. Religious freedom survived, despite some conciliations of Roman Catholic opinion. Freedom of internal trade and encouragements to technical innovation allied the state with commercial growth. Sales of church land were confirmed, and rural France emerged as a nation of strongly independent peasant proprietors.

Napoleon's conquests cemented the spread of French revolutionary legislation to much of western Europe. The powers of the Roman Catholic church, guilds, and manorial aristocracy came under the gun. The old regime was dead in Belgium, western Germany, and northern Italy.

Finally, wider conquests permanently altered the European map. Napoleon's kingdoms consolidated scattered territories in Germany and Italy, and the welter of divided states was never restored. These developments, but also resentment at Napoleonic rule, sparked growing nationalism in these regions and also in Spain and Poland. Prussia and Russia, less touched by new ideologies, nevertheless introduced important political reforms as a means of strengthening the state to resist the Napoleonic war machine. Prussia expanded its school system and modified serfdom; it also began to recruit larger armies. Britain was less affected, protected by its powerful navy and an expanding industrial economy that ultimately helped wear Napoleon down; but, even in Britain, French revolutionary example spurred a new wave of democratic agitation.

The Congress of Vienna

In 1814–15 the victorious powers convened at the Congress of Vienna to try to put Europe back together, though there was no thought of literally restoring the world that had existed before 1789. Regional German and Italian states were confirmed as a buffer to any future French expansion. Prussia gained new territories in western Germany. Russia took over most of Poland (previously divided, in the late 18th century, until Napoleon's brief incursion). Britain acquired some former French, Spanish, and Dutch colonies (including South Africa). The Bourbon dynasty was restored to the French throne in the person of Louis XVIII, but revolutionary laws were not repealed, and a parliament, though based on very narrow suffrage,



Europe after the Congress of Vienna (1815). Inset shows the greatest extent of the Napoleonic empire (1812).

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proclaimed a constitutional monarchy. The Treaty of Vienna disappointed nationalists, who had hoped for a new Germany and Italy, and it certainly daunted democrats and liberals. However, it was not reactionary, nor was it punitive as far as France was concerned. Overall, the treaty strove to reestablish a balance of power in Europe and to emphasize a conservative political order tempered by concessions to new realities. The former was remarkably successful, preserving the peace for more than half a century, the latter effort less so.

The conservative reaction. Conservatism did dominate the European political agenda through the mid-1820s. Major governments, even in Britain, used police agents to ferret out agitators. The prestige of the Roman Catholic church soared in France and elsewhere. Europe's conservative leader was Prince von Metternich, chief minister of the Habsburg monarchy. Metternich realized the fragility of Habsburg rule, not only wedded to church and monarchy but also, as a polyglot combination of German, Hungarian, and Slavic peoples, vulnerable to any nationalist sentiment. He sedulously avoided significant change in his own lands and encouraged the international status quo as well. He sponsored congresses at several points through the early 1820s to discuss intervention against political unrest. He was particularly eager to promote conservatism in the German states and in Italy, where Austrian administration of northern provinces gave his regime a new stake.

Nevertheless, in 1820 revolutionary agitation broke out in fringe areas. Risings in several Italian states were put down. A rebellion in Spain was also suppressed, though only after several years, foreshadowing more than a century of recurrent political instability; the revolution also confirmed Spain's loss of most of its American colonies, which had first risen during the Napoleonic occupation. A Greek revolution against Ottoman control fared better, for Greek nationalists appealed to European sympathy for a Christian nation struggling against Muslim dominance. With French, British, and Russian backing, Greece finally won its independence in 1829.

Liberal agitation began to revive in Britain, France, and the Low Countries by the mid-1820s. Liberals wanted stronger parliaments and wider protection of individual rights. They also sought a vote for the propertied classes. They wanted commercial legislation that would favour business growth, which in Britain meant attacking Corn Law tariffs that protected landlord interests and kept food prices (and so wages) artificially high. Belgian liberals also had a nationalist grievance, for the Treaty of Vienna had placed their country under Dutch rule.

Liberal concerns fueled a new round of revolution in

Liberal gains in the 1830s

1830, sparked by a new uprising in Paris. The French monarchy had tightened regulation of the press and of university professors, producing classic liberal issues. Artisans, eager for more political rights, also rose widely against economic hardship and the principles of the new commercial economy. This combination chased the Bourbon king, producing a new and slightly more liberal monarchy, an expanded middle-class voting system, and some transient protections for freedom of the press; the new regime also cut back the influence of the church. Revolution spread to some German and Italian states and also to Belgium, where after several years an independent nation with a liberal monarchy was proclaimed. Britain was spared outright revolution, but massive agitation forced a Reform Bill in 1832 that effectively enfranchised all middle-class males and set the framework for additional liberal legislation, including repeal of the Corn Laws and municipal government reform, during the next decade.

Europe was now divided between a liberal west and a conservative centre and east. Russia, indeed, seemed largely exempt from the political currents swirling in the rest of the continent, partly because of the absence of significant social and economic change. A revolt by some liberal-minded army officers in 1825 (the Decembrist revolt) was put down with ease, and a new tsar, Nicholas I, installed a more rigorous system of political police and censorship. Nationalist revolt in Poland, a part of the 1830 movement, was suppressed with great force. Russian diplomatic interests continued to follow largely traditional lines, with recurrent warfare with the Ottoman Empire in an effort to gain territory to the south. Only after 1850 did the Russian regime seriously rethink its adamantly conservative stance.

This pattern could not prevail elsewhere in Europe. Scandinavian governments moved toward increasing liberalism by expanding the power of parliaments, a development that was completed in the late 1840s; the Dutch monarchy did the same. Elsewhere, the next major step resulted once again from a series of revolutions in 1848, which proved to be western Europe's final revolutionary round.

The revolutions of 1848. France's monarchy had turned toward greater repression in the 1840s, spurring new liberal agitation. Artisan concerns also had quickened, against their loss of status and shifts in work conditions following from rapid economic change; a major recession in 1846–47 added to popular unrest. Some socialist ideas spread among artisan leaders, who urged a regime in which workers could control their own small firms and labour in harmony and equality. A major propaganda campaign for wider suffrage and political reform brought police action in February 1848, which in turn prompted a classic street rising that chased the monarchy (never to return) and briefly established a republican regime based on universal manhood suffrage.

Revolt quickly spread to Austria, Prussia, Hungary, Bohemia, and various parts of Italy. These risings included most of the ingredients present in France, but also serious peasant grievances against manorial obligations and a strong nationalist current that sought national unification in Italy and Germany and Hungarian independence or Slavic autonomy in the Habsburg lands. New regimes were set up in many areas, while a national assembly convened in Frankfurt to discuss German unity.

The major rebellions were put down in 1849. Austrian revolutionaries were divided over nationalist issues, with German liberals opposed to minority nationalisms; this helped the Habsburg regime maintain control of its army and move against rebels in Bohemia, Italy, and Hungary (in the last case, aided by Russian troops). Parisian revolutionaries divided between those who sought only political change and artisans who wanted job protection and other gains from the state. In a bloody clash in June 1848, the artisans were put down and the republican regime moved steadily toward the right, ultimately electing a nephew of Napoleon I as president; he, in turn (true to family form), soon established a new empire, claiming the title Napoleon III. The Prussian monarch turned down a chance to head a liberal united Germany and instead used his army to chase the revolutionary governments, aided by divisions between liberals and working-class radicals (including the socialist Karl Marx, who had set up a newspaper in Cologne).

The political stage in 1850

Despite the defeat of the revolutions, however, important changes resulted from the 1848 rising. Manorialism was permanently abolished throughout Germany and the Habsburg lands, giving peasants new rights. Democracy ruled in France, even under the new empire and despite considerable manipulation; universal manhood suffrage had been permanently installed. Prussia, again in conservative hands, nevertheless established a parliament, based on a limited vote, as a gesture to liberal opinion. The Habsburg monarchy installed a rationalized bureaucratic structure to replace localized landlord rule. A new generation of conservatives came to the fore—Metternich had been exiled by revolution—who were eager to compromise with and utilize new political forces rather than oppose them down the line. Finally, some new political currents had been sketched. Socialism, though wounded by the failure of the revolutions, was on Europe's political agenda, and some feminist agitation had surfaced in France and Germany. The stage was set for rapid political evolution after 1850, in a process that made literal revolution increasingly difficult.

The years between 1815 and 1850 had not seen major diplomatic activity on the part of most European powers, Russia excepted. Exhaustion after the Napoleonic Wars combined with a desire to use diplomacy as a weapon of internal politics. Britain continued to expand its colonial hold, most notably introducing more direct control over its empire in India. France and Britain, though still wary of each other, joined in resisting Russian gains in the Middle East. France also began to acquire new colonial holdings, notably by invading Algeria in 1829. Seeds were being planted for more rapid colonial expansion after mid-century, but the period remained, on the surface, rather quiet, in marked contrast to the ferment of revolution and reaction during the same decades. (P.N.S.)

ROMANTICISM AND REALISM

The legacy of the French Revolution. To make the story of 19th-century culture start in the year of the French Revolution is at once convenient and accurate, even though nothing in history "starts" at a precise moment. For although the revolution itself had its beginnings in ideas and conditions preceding that date, it is clear that the events of 1789 brought together and crystallized a multitude of hopes, fears, and desires into something visible, potent, and irreversible. To say that in 1789 reform becomes revolt is to record a positive change, a genuine starting point. One who lived through the change, the Duke de La Rochefoucauld-Liancourt, was even sharper in his vision when (as the story goes) he answered Louis XVI, who had asked whether the tumult outside was a revolt: "No, sire, it is a revolution." In cultural history as in political, significance is properly said to reside in events; that is, in the acts of certain men or the appearance of certain works that not only embody the feelings of the hour but also prevent other acts or works from having importance or effect. To list some examples: the year 1790 saw the appearance of Goethe's *Faust, a Fragment,* of Burke's *Reflections on the Revolution in France,* of Blake's *Marriage of Heaven and Hell,* and of Kant's *Critique of Judgment.* In these works are found the Romanticist view of human destiny, of the state, of moral energy, and of aesthetics. The remainder of the decade goes on to show that it belongs to a new age; it gave the world Goya's "Caprichos" and the portrait of the Duchess de Alba, Beethoven's *Piano Sonata in C Minor (Pathétique),* Hölderlin's *Hyperion,* the beginning of August Wilhelm von Schlegel and Ludwig Tieck's translation of Shakespeare into German, Schelling's *Nature Philosophy,* Herder's *Letters on the Progress of Mankind,* Wordsworth and Coleridge's *Lyrical Ballads,* Schiller's *Wallenstein,* and Schleiermacher's *On Religion: Speeches to Its Cultured Despisers.* These are so many evidences of a new direction in thought and culture.

To say, then, that the cultural history of the later modern age—1789 to the present—begins with the French Revolution is to discuss that revolution's ideas rather than

the details of its onward march during its first 10 years. These ideas are the recognition of individual rights, the sovereignty of the people, and the universal applicability of this pair of propositions. In politics the powerful combination of all three brings about a permanent state of affairs: "the revolution" as defined here has not yet stopped. It continues to move the minds of men, in the West and beyond. The revolution is "dynamic" because it does not simply change rulers or codes of law but also arouses a demand and a hope in every individual and every people. When the daily paper tells of another new nation born by breaking away, violently or not, from some other group, the revolutionary doctrine of the sovereignty of the people may be observed still at work after two centuries.

Cultural nationalism. The counterpart of this political idea in the 19th century is cultural nationalism. The phrase denotes the belief that each nation in Europe had from its earliest formation developed a culture of its own, with features as unique as its language, even though its language and culture might have near relatives over the frontier. Europe was thus seen as a bouquet of diverse flowers harmoniously bunched, rather than as a uniform upper-class civilization stretching from Paris to St. Petersburg, from London to Rome, and from Berlin to Lisbon—wherever "polite society" could be found, a society acknowledging the same artistic ideals, speaking French, and taking its lead from the French court and culture. In still other words, the revolutionary idea of the people as the source of power ended the idea of a cosmopolitan Europe.

The "uniform" conception presupposed a class or elite transcending boundaries; the "diverse" implied a number of distinct nations made up of citizens attached to their native soil and having an inborn and exclusive understanding of all that had been produced on it. In each nation it is the people as a whole, not just the educated class, that is deemed the creator and repository of culture; and that culture is not a conscious product fashioned by the court artists of the moment: it is the slow growth of centuries. This view of Europe explains one of the great intellectual forces of the postrevolutionary era—the passion for history. An emotion that may be called cultural populism replaced the devotion to a single horizontal, Europe-wide, and "sophisticated" civilization. These vertical national cultures were "popular" not only in their scope but also in their simplicity.

Beginnings of cultural nationalism

This new outlook, though propagated by the revolution, began as one of those subdued feelings mentioned earlier, as undercurrents beneath Enlightenment doctrine. In England and Germany especially, a taste developed for folk literature—the border ballads, the legends and love songs of the people, their dialects and superstitions. Educated gentlemen collected and published these materials; poets and storytellers imitated them. Horace Walpole in *The Castle of Otranto,* Macpherson in *Ossian,* Chatterton in his forgeries of early verse, and Goethe in his lyrics exploited this new vein of picturesque sentiment. A scholar such as Herder or a poet-dramatist such as Schiller drew lessons of moral, psychological, and philosophical import from the wisdom found in the subculture of *das Volk.* The folk or people was not as yet very clearly defined, but the revolution would shortly take care of this omission.

In France, where the revolution occurred, the situation was somewhat different. There were no collectors of border ballads or exploiters of Gothic superstitions. France by 1789 had been for more than a century the cultural dictator of Europe, and it is clear that in England and Germany the search for native sources of art was stimulated by the desire to break the tyranny of the French language and literature. The rediscovery of Shakespeare, for example, was in part a move in the liberation from French classical tragedy and its rigid limitations of subject matter and form.

Simplicity and truth. Yet cultural nationalism was also the expression of a genuine desire for truth. This in turn implied the release of feelings that the confidence of the Enlightenment in the power of reason had tended to suppress. Two 18th-century figures tapped this fount of emotion, Samuel Richardson and Jean-Jacques Rousseau. The novels of Richardson, in which innocent girls are portrayed as withstanding the artful seductions of titled gentlemen, might be said to foreshadow in symbolic form the struggle between high cosmopolitan culture and the new popular simplicity. These novels were best-sellers in France, and Rousseau's *Nouvelle Héloïse* followed in their wake, as did the bourgeois dramas of Diderot, Beaumarchais's satirical comedies about the plebeian Figaro, and the peasant narratives of Restif de la Bretonne, to mention only the most striking exemplars of the new simplicity.

At the very centre of sophistication the simple life became a fad, the French court (including Marie-Antoinette) dressing up and playing at the rustic existence of milkmaids and shepherds. However silly the symptoms, the underlying passion was real. It was the periodic urge of complex civilizations to strip off the social mask and recover the happiness imagined as still dwelling among the humble. What was held up to admiration was honesty and sincerity, the strong and pure feelings of people unspoiled by court and city life. Literature therefore came to express an acute sensitivity to scenes of undeserved misfortune, of heroic self-sacrifice, of virtue unexpectedly rewarded—a sensitivity marked by tearfulness, actual or "literary."

Back-to-nature movement

This surge of self-consciousness about sophisticated culture has often been confused with an idealization of primitive man and attributed to Rousseau. But contrary to common opinion, the so-called back-to-nature movement does not at all echo the noble-savage doctrine of the 17th century. Rousseau's attack on "civilization," which evoked such a powerful response in the latent feelings of his contemporaries, goes with a characterization of the savage as stupid, coarse, and amoral. In Rousseau and his abettors, what is preached is the simple life. What nature and the natural really are remains to be found by trial and error—the fit methods and forms of religion, marriage, child rearing, hygiene, and daily work.

Populism. It is easy to see in these beliefs and sentiments (which often passed into sentimentality) additional materials for the populism that the revolution fostered. Revolution, to begin with, is also an urge to simplify. The revolutionary style was necessarily populist—Marat's newspaper was called *L'Ami du peuple* ("The Friend of the People"). The visible signs that a revolution had occurred included the wearing of natural hair instead of wigs and of common workmen's trousers instead of silk breeches, as well as the use of the title of *citoyen* instead of *Monsieur* or any other term of rank. Now, equality coupled with sincerity and simplicity logically leads to fraternity, just as honest feeling coupled with devotion to the people leads to puritanism: a good and true citizen behaves like a moral man. He is, under the revolutionary principles, a responsible unit in the nation, a conscious particle of the will of the sovereign people, and as such his most compelling obligation is love of country—patriotism.

With this last word the circle of ideas making up the cultural ambient of the French Revolution might seem to be complete. However, in the effort to trace back and interweave the strands of feeling and opinion that make up populism, one must not overlook the first political axiom of revolutionary thought, which is the recognition of individual rights. Their source and extent is a subject for political theory. The recognition of the individual goes with the assertion that his freedom rests on natural law, a potent idea, as we know who have witnessed the vast extension of rights far beyond their first, political meaning. Here the concern is with their cultural role, which can be simply stated: individual rights generate individual*ism* and magnify it. That *-ism* denotes both an attitude and a doctrine, which together amount to a passionate belief: every human being is an object of primary interest to himself and in himself; he is an end in himself, not a means to the welfare of class or state or to other group purposes. Further, the truly valuable part of each individual is his uniqueness, which he is entitled to develop to the utmost, free of oppression from the government or from his neighbours. That is why the state guarantees the citizen rights as against itself and other citizens. Again, this power accrues to him for himself because he is inherently important—not because he is son or father, peasant or overlord, member of a clan or a guild.

Doctrine of individualism

These ideas shift the emphasis of several thousand years of social beliefs and let loose innumerable consequences. Individualism lowers the value of tradition and puts a premium on originality; it leads to the now familiar "cult of the new"—in art, manners, technology, and social and political organization. True, the individual soul had long been held unique and precious by Christian theology, but Christian society had not extended the doctrine to every man's mundane comings and goings. Nor were his practical rights and powers attached to him as a man but, rather, to his status. Now the human being as such was being officially considered self-contained and self-propelling; it was a new regime and its name was liberty.

Nature of the changes. The contents and implications of these powerful words—liberty, equality, and fraternity, individualism and populism, simplicity and naturalness—enable us to delineate the cultural situation of Europe at the dawn of the era under review. Yet these continuing ideas necessarily modified each other and in different times and countries were subject to still other influences.

For example, the active phase of the revolution in France—say, 1789 to 1804—was influenced by the classical education of most of its public men. They had been brought up on Roman history and the tales of Plutarch's republican heroes, so that when catapulted into a republic of their own making, the symbols and myths of Rome were often their most natural means of expression. The eloquence of the successive national assemblies is full of Roman allusions. Later, when General Bonaparte let it be seen that he meant to rule France, he was denounced in the Chamber as a Caesar; when he succeeded, he took care to make himself consul (a title of the ancient Roman Republic), flanked by two other consuls of lesser rank. The title was meant to show that no Caesar was in prospect.

Changes in the fine arts

In the fine arts this Roman symbolism facilitated a thorough change of taste and technique. The former "grand style" of painting had been derived from royal and aristocratic elegance, and its allusions to the ancient classical past were gentle and distant, architectural and mythological. Now, under the leadership of the painter David, the great dramatic scenes of ancient history were portrayed in sharp, uncompromising outlines that struck the beholder as the utmost realism of the day.

In David's "Death of Socrates" and "Oath of the Horatii" civic and military courage are the respective subjects; in his pencil sketches of the victims of the Terror as they were led to execution, reportorial realism dominates; and, in his designs for the setting of huge popular festivals, David, in collaboration with the musicians Méhul and Grétry, provided the first examples of an art in scale with the new populism: the courtly taste for intimate elegance and subtle manners gave way to the more striking, less polished large-scale feelings of a proud nation.

It must be added, however, that except for a few canvases and a few tunes (including the "Marseillaise") the quality of French Revolutionary art was not on a par with its aspirations. Literature in particular showed the limitations under which revolutionary artists must work: political doctrine takes precedence over truth, and the broad effects required to move the masses encourage banality. There is no French poetry in this period except the odes of Chénier, whom the revolution promptly guillotined, as it did France's greatest scientist, Lavoisier. The French stage was flourishing but not with plays that can still be read. The revolutionary playwrights only increased the dose of sentiment and melodrama that had characterized plays at the close of the old regime. The aim was to hold up priests and kings to execration and to portray examples of superhuman courage and virtue. Modern operagoers who know the plot of Beethoven's *Fidelio* can judge from that sample what the French theatre of the revolutionary years thrived on. Others can imagine for themselves Molière's *Misanthrope* rewritten so as to make Alceste a pure patriot and hero, undermined by the intrigues of the vile courtier Philinte.

It may seem odd that once the revolution was under way there should be such persistent indignation and protest against courtiers, priests, and kings and such fulsome homage paid to virtue and patriotism. What accounts for it is the difficulty of transforming culture overnight. People have to be persuaded out of old habits—and must keep on persuading themselves. Even politically, the revolution proceeded by phases and experienced regressions. Manners and customs themselves did not change uniformly, as one can see from portraits of Robespierre at the height of his power wearing a short wig and knee breeches, republican and Rousseauist though he was.

Bonaparte's coup d'état

Napoleon's influence. After Bonaparte's coup d'état, tension eased as the high revolutionary ideals dropped to a more workaday level, just as the puritanism was replaced by moral license. The general's expedition to Egypt in 1798 before his self-elevation to power introduced a new style competing with the ancient Roman in costume and furnishings; the Middle East became fashionable and out of the cultural contact came the new science of Egyptology. The Roman idea itself shifted from republic to empire as the successful general and consul Bonaparte made himself into the emperor Napoleon in 1804.

The emperor had an extraordinary capacity for attending to all things, and he was concerned that his regime should be distinguished in the arts. He accordingly gave them a sustained patronage such as a revolutionary party rent by internal struggles could not provide. Napoleon, nonetheless, had tastes of his own, and he had to control public opinion besides. In literature (he had been a poet and writer of novels in his youth), he relished the Celtic legends of *Ossian* and encouraged his official composer Lesueur in the composition of the opera *Ossian ou les Bardes*. In painting, he favoured the surviving David and the younger men Gros and Géricault, both "realists" concerned with perpetuating the colour and drama of imperial life. But to depict matters of contemporary importance on the stage (except perhaps in the ballet, which was flourishing) did not prove possible, for the stage must present genuine moral conflict if it is to produce great works, and moral issues are not discussable under a political censorship.

The paradox of the Napoleonic period is that its most lasting cultural contributions were side effects and not the result of imperial intentions. Two of these contributions were books. One, Chateaubriand's *The Genius of Christianity* (1802), was a long tract designed to make the author's peace with the ruler and revigorate Roman Catholic faith. The other, Madame de Staël's *Germany* (1810), was a description of the new and thriving literature, philosophy, and popular culture in Germany. Napoleon prohibited the circulation of the book in France, but its message percolated French public opinion nonetheless. Two other sources of future light were the Idéologues, a group of philosophers who were scientific materialists particularly concerned with abnormal psychology, and Napoleon Bonaparte himself, or rather the figure of Napoleon as seen by his age after Waterloo.

General character of the Romantic movement. The mention of Waterloo (1815) suggests the need to make clear a number of chronological discrepancies. It has been possible so far to discuss the general shift in the temper of European life without naming fixed points. It sufficed to say "before or after 1789" or "from 1789 to the Napoleonic empire." However, from now on the generations of culture makers and the dates of some of their works must be duly situated, without on that account losing sight of unities and similarities in the onward march of artistic and intellectual movements. If, for example, one considers the poets called Romantic or Romanticist, one finds that Goethe came to maturity in the 1770s, when the English Romantics were just beginning to be born. Their French, Italian, Russian, Polish, and Spanish counterparts were, in turn, born about the year 1800, when the English were already in mid-career. The same irregularity in the onset of Romanticism is found in the other arts, and it is complicated (at least superficially) by the names given to various movements and persons in the different countries of Europe. Thus, in Germany the term *Romantismus* is applied to only a small group of writers, and Goethe and Schiller are called classic. In Poland and in Russia, classic is likewise the label for the great writers whose characteristics in fact align them with the Romantics elsewhere.

Chronological discrepancies in the Romantic movement

All these accidents of birth and nomenclature can be

taken in stride by remembering the patterns found in each country or decade and the reasons for their appearance at that time and place. Within the slightly more than half century between 1789 and 1848, the phenomenon of Romanticism occurred and developed its first phase. Those who made it may have come early or late, belonged to this or that nationality, proved to be originators or synthesizers of existing elements—all such considerations appertain to individual biography or the history of a particular art or nation. What matters in the evolution of European culture considered as a whole is the orchestration of all the voices as they come in to swell the ensemble.

The main purport of the Romantic movement is commonly said to be a revolt against 18th-century rationalism and a resulting variety of new attitudes and activities: a turning in upon the self, a love of nature, the rediscovery of the Middle Ages, the cult of art, a taste for the exotic, a return to religion, a fresh sense of history, a yearning for the infinite, a maudlin sentimentality, an overvaluing of emotion as such, a liberal outlook in politics, a conservative outlook, a reactionary outlook, a socialist-utopian outlook, and several other "characteristic features."

It is clear that not all these can be equally true, characteristic, or important, since some contradict the others. At the same time it was inevitable that so sweeping a cultural revolution as Romanticism should contain incompatible elements. For instance, the political opinions enumerated above did in fact win the allegiance of different groups among the Romantic artists and thinkers for a longer or shorter time. But—to take note of other supposed definitions—not all Romanticists returned to religion: Goethe and Berlioz were pantheists; Byron and Heine, atheists; and Victor Hugo, a sort of Swedenborgian. As for sentimentality, its occurrence was rather a hangover from the 18th century than a new fashion of feeling, for the Romantic cult of art and of strong emotion goes dead against the weak sentimental mood. Similarly, the taste for history, for the Middle Ages, and for the exotic shows a strong curiosity about the particulars of what is real though ignored by previous conventions. All critics, however, are agreed upon one Romantic trait: individualism. And it is here that the figure of Napoleon plays its cultural role.

Incompatible elements of Romanticism

Napoleon, or more exactly Bonaparte, the revolutionary general, the overthrower of old monarchies and creator of new national republics, the organizing genius who rescued France from chaos and who held off the reactionary forces leagued against him throughout Europe—that figure is the one that inspired Beethoven's *Eroica* symphony, Balzac's and Stendhal's heroes, and the poems, paintings, and compositions of many others. Here was the model of the new man. He was the self-made man and the man of genius. His career was the manifestation of will and intelligence overcoming the greatest imaginable resistance. He typified the individual challenging the world and subduing it by his genius. A movement that numbered as many artists and geniuses as did Romanticism was bound to find in Napoleon the individual par excellence or, as might be said in modern jargon, a supremely autonomous personality. This perception explains why nearly all the great names of the first half of the 19th century are found on the roster of those who praised Napoleon—from Beethoven and Byron to Hazlitt and Stendhal and Manzoni. Some who were politically his enemies—Sir Walter Scott, for example—nonetheless respected and pondered over the miracle of his achievements. No comparable attention has been paid to the dictators of the 20th century, a fact sufficiently explained by the real difference between them and Napoleon. Stendhal, who as a military *intendant* took part in the Russian campaign of 1812, stated that difference: Napoleon was a man of thought and vision, and not merely a successful soldier and politician. In everything he touched, he showed originality of conception, a stupendous grasp of detail in execution, and the utmost speed in acting out his vision. This sequence, translated to other realms, was the very pattern of the artist-creator's imagination. It also seemed the vindication of individualism as a philosophy of life: open the world to the individual and the world will witness marvels unimagined before.

These remarks about Napoleon should convey a sense of the Romantics' attitude toward themselves and their situation. It is true that culturally they stood in opposition to their immediate forebears. All generations do the same; yet it is not always true that out of the conflict comes great art. The Romanticists had an advantage in undergoing or being emotionally close to a quarter century of violent change. Besides being a stimulus, the tumult of battle and political overturns did its share to clear the ground for artistic innovation. When habits and expectations are repeatedly upset and frustrated in the broad public realm, the general mind opens up to novelty offered in other realms. That is one avenue of cultural, stylistic, and emotional change. When Stendhal was expounding Romanticism to the French in 1822, he argued that to go on writing in the Neoclassic vein was "to provide literary pleasure for one's grandfather." His remark was readily understood—at least by his young readers. Mighty events had dug a chasm between past and present, making plain the remoteness of the 18th century.

The Romantics' attitude toward themselves

And yet a paradox remains. When a Romantic artist first published his innovative work—say Wordsworth with the *Lyrical Ballads* of 1798—he had to wait a good while for a hearing, though he might have expected that readers would share his conviction that the style and forms of 18th-century Neoclassicism were dead. Already in 1783 Blake had written of contemporary English verse that "The sound is forced, the notes are few." But these two poets' estimate was, so to speak, the professional's view of the state of the art. The public, no longer the small, concentrated court-and-town coterie, lagged behind this perception. It is a cliché that such artists are ahead of their time. It would be more accurate to say that it is the public which lags behind its own time.

This phenomenon is characteristic of the modern period generally, because through social and educational emancipation the audience for things artistic and intellectual has steadily grown larger. That fact complicates the study of the Romantic movement: When did it conquer public opinion in different countries and why at different times? In England and Germany one can point to the 1790s: Blake, Wordsworth, and Coleridge; Goethe (with the first fragment of *Faust*), Schiller, Herder, Jean Paul (Richter), Beethoven, Tieck, Wackenroder, Hölderlin, Schelling, Schleiermacher, and the "rediscovery" of Shakespeare mark the advent of the new age.

In Italy, France, and Russia, the decisive years opened in 1820. They are signalized in Russia by the abundant poetic output of Pushkin, in Italy by the work of Manzoni and Leopardi and by the surrounding discussions of literary theory, and in France by the poems of Lamartine, Vigny, Musset, Victor Hugo, and Mme Desbordes-Valmore. The paintings of Delacroix, the first compositions of Berlioz, and Balzac's *Chouans* show that a new spirit was at work. Finally, in the 1830s, Poland—through its poet and novelist Mickiewicz—and Spain—through the works of Rivas, Espronceda, José de Larra, and Zorrilla—joined the rest of Europe in its richest artistic flowering since the Renaissance: the leading nations can boast one or more Romantic artists of the first magnitude.

Romanticism in literature and the arts. The fundamental Romantic purpose was to grasp and render the many kinds of experience that classicism had neglected or had stylized. Romanticism was the first upsurge of realism—exploratory and imaginative as to subject matter and inventive as to forms and techniques. The exploration of reality surveyed both the external world of peoples and places and the internal world of man. The Scottish and medieval novels of Sir Walter Scott, beginning with *Waverley* in 1814, illustrate the range of the new curiosity, for Scotland was a "wild" place, outside the centres of civilization, and the Middle Ages were similarly "barbarous" and distant in time. When Byron or Chateaubriand went to the Middle East or Goethe to Italy, it was not in the tradition of gentlemen's tourism; it was in the spirit of the cultural explorer. Byron, for one, by using "the Isles of Greece" and the Mediterranean as settings for his wildly popular narrative poems, was developing in the Western mind a new interest, a new sense that the "exotic" was as real, as important, as Paris or London. In all these

The fundamental Romantic purpose

writers, factual detail is essential to the new sort of effect: the scenery is observably true, and so is the history, given through local colour. As Byron said when criticized: "I don't care two lumps of sugar for my poetry, but my costume is correct." Blake, 20 years earlier, had taken a stand against Sir Joshua Reynold's academic doctrine that the highest form of painting depicted the broadest general truth. Said Blake: "To particularize is the only merit."

Particulars, moreover, are all equally proper for the artist; the use he makes of them is what matters. When Wordsworth and Coleridge sought to revivify English poetry, they hit upon two divergent kinds of subject: Coleridge took superstition and the folk tale and wrote "The Rime of the Ancient Mariner" in the form of an old ballad; Wordsworth took the modern street ballad—a kind of rhymed newspaper—and produced his versified incidents of common life in common speech. In France, where the division of the vocabulary into "noble" and "common" (*i.e.,* unfit for poetry) had been made and recorded in dictionaries, the Romantics led by Hugo used the prohibited words whenever they saw fit. Hugo's verse drama *Hernani* (1830) created a scandal in the audience when the heroine was heard to speak of her handkerchief and when a character did not use a roundabout phrase about "the march of the hours" to say: "It is midnight."

The rediscovery of Shakespeare

The importance of such details can hardly be exaggerated and can perhaps be best understood by recalling what the rediscovery of Shakespeare meant to the Romantics. His rise from grudging esteem, even in England, to European idolatry by 1830 had a significance beyond the one already mentioned of serving to put down French classical tragedy and, with it, French cultural tyranny. The German scholar, critic, and playwright Lessing was among the first to use Shakespeare for that purpose, but the arguments in his theatre reviews, called *Hamburgische Dramaturgie,* sprang from critical genius and not mere national resentment. Shakespeare spelled freedom from narrow conventions—the set verse form in couplets, the lofty language and long declamations, the adherence to verse throughout, the exclusion of low characters, comic effects, and violent action—or, in a word, from royal and artistic etiquette.

What the rediscovery and idolization of Shakespeare meant (and not to poets and playwrights alone—witness his enormous influence on Berlioz) was the right of the artist to adapt or invent forms to suit contents, to use words formerly excluded from poetic diction, loosen the joints of grammar and metric (or the canons of any art), follow the promptings of his spirit (tragic or gay, vulgar or mysterious, but in any case venturesome), and see where this emancipation from artificial rules led the muse. There was danger in freedom, as always; the conventions ensure safety. The aim of the Romantic genius, however, was not to play safe or even to succeed; it was to explore and invent, multiply modes of feeling and truth, and thereby breathe new life into a dead or dying culture. The motto was not common sense but courage. This resolve explains why the men who came to worship Shakespeare also rediscovered Rabelais and Villon and revalued Spinoza, the lone dissenter who had revered a God pervading the cosmos; Benvenuto Cellini, the fearless artist at grips with the principalities and powers; and "Rameau's Nephew," the ambiguous hero of Diderot's posthumous dialogue, a strange figure disturbingly in touch with the dark forces of the creative unconscious.

Drama. With so much feeling astir and so many novel ideas being agitated, it might seem logical to expect a flourishing school of Romantic drama. Yet only a few isolated works, more interesting than irreplaceable, compose the dramatic output of the Romanticists—Shelley's *Cenci,* Byron's *Manfred,* and Kleist's brilliant pieces in several genres. Ironically, Shakespeare's new role as emancipator had a curiously paralyzing effect on the theatre down to the middle of the century and beyond. In England, poet after poet tried his hand at poetic drama, only to fail from too anxious a desire to be Shakespearean. On the Continent, various misconceptions about him and old habits of classical tragedy prevented a new drama from coming to life. Victor Hugo's plays contained brilliant verse, and their form influenced grand opera (Wagner's no less than Verdi's), but the fact remained: the dramatic quality could be found everywhere in Romanticist art except on the stage.

Reflection on this point suggests that, quite apart from Shakespeare, the very concern of the Romantics with exploring the inner and outer worlds simultaneously hampered the playwright. Perhaps great drama requires that one or the other world be taken as settled so that conflict, which is the essence of drama, develops between a strong new force and a solid resistance. Be that as it may, the Romantics found themselves in an age when both inner and outer worlds were in flux and from that double uncertainty derived their creative impetus.

Painting. This generality holds for the painters as well; their "reality," too, was by no means "given," so that the notation of fresh detail and the study of new means to transmute the visible into art occupied all those who came after David. Goya led the way in Spain by depicting the vulgarity of court figures and the horrors of the Peninsular War. In England, Constable painted country scenes with a vividness at first unacceptable to connoisseurs. He had to argue with his patron, Sir George Beaumont, about the actual colour of grass. To prove that it was not of the conventional brownish tint used by academicians, he seized a violin, ran out of the room with it, and laid it on the lawn, forcing the unaccustomed eye to perceive the difference between chlorophyll and old varnish. At the same time, Géricault astonished the Parisians by painting, in harrowing detail, "The Raft of the Medusa," not an antique and noble subject but a recent event: the survivors of a shipwreck adrift and starving on a raft.

The new "reality" in painting

The young Delacroix was emboldened by the example and, inspired also by the work of his English friend Bonington, began to paint contemporary scenes of vivid realism—*e.g.,* the Turkish massacre of the Greek peasants at Chios. Later, Delacroix was to visit Morocco (exoticism again) and to discover there the secret of coloured shadows and other pre-Impressionist techniques. His English counterpart, J.M.W. Turner, was pursuing the same goal of realistic truth, though along a different path that nonetheless also led to Impressionism—and beyond. When asked one day why he had pasted a scrap of black paper on a portion of his canvas, he replied that ordinary pigment was not black enough. And he added: "If I could find something even blacker, I would use that."

Sculpture and architecture. No similar transformations of the visual occurred in sculpture or architecture. Canova and Thorvaldsen continued to produce figures and busts on Neoclassical lines; and only Barye, the great sculptor of animals, and Rude, the creator of the Marseillaise panel on the Arc de Triomphe, showed any signs of the new passions. As for architecture, it may have been the love of history that prevented distinctive work. Pugin and Viollet-le-Duc did grasp the principles of what a new style should be, the former's love of Gothic reinstating the merit of framework construction and the latter's breadth of vision as a restorer leading him to predict that iron construction would one day pass from mere utility to high art.

It was actually in railway construction that the seeds of a new architecture were sown. Tunnels and bridges and terminals were needed as early as the mid-1830s, and unassuming engineers such as the Brunels and Robert Stephenson set to work to design them. All they had for solving the new and awkward problems of topography, speed, and cost were the ideas they drew from machinery and the vulgar materials, chiefly wood and iron, that they had learned how to handle in industry. The results were often remarkable, and they remained to inspire the makers of 20th-century steel and concrete architecture.

Music. It may seem as if the art of music by its nature would not lend itself to the exploration and expression of reality characteristic of Romanticism, but that is not so. True, music does not tell stories or paint pictures, but it stirs feelings and evokes moods, through both of which various kinds of reality can be suggested or expressed. It was in the rationalist 18th century that musicians rather mechanically attempted to reproduce stories and subjects in sound. These literal renderings naturally failed, and the Romanticists profited from the error. Their discovery of

Changes in the relationship between music and literature

new realms of experience proved communicable in the first place because they were in touch with the spirit of renovation, particularly through poetry. What Goethe meant to Beethoven and Berlioz and what German folk tales and contemporary lyricists meant to Weber, Schumann, and Schubert are familiar to all who are acquainted with the music of these men.

There is, of course, no way to demonstrate that Beethoven's *Egmont* music—or, indeed, its overture alone—corresponds to Goethe's drama and thereby enlarges the hearer's consciousness of it; but it cannot be an accident or an aberration that the greatest composers of the period employed the resources of their art for the creation of works expressly related to such lyrical and dramatic subjects. Similarly, the love of nature stirred Beethoven, Weber, and Berlioz, and here too the correspondence is felt and persuades the fit listener that his own experience is being expanded. The words of the creators themselves record this new comprehensiveness. Beethoven referred to his activity of mingled contemplation and composition as *dichten,* making a poem; and Berlioz tells in his *Memoires* of the impetus given to his genius by the music of Beethoven and Weber, by the poetry of Goethe and Shakespeare, and not least by the spectacle of nature. Nor did the public that ultimately understood their works gainsay their claims.

It must be added that the Romantic musicians—including Chopin, Mendelssohn, Glinka, and Liszt—had at their disposal greatly improved instruments. The beginning of the 19th century produced the modern piano, of greater range and dynamics than theretofore, and made all wind instruments more exact and powerful by the use of keys and valves. The modern full orchestra was the result. Berlioz, whose classic treatise on instrumentation and orchestration helped to give it definitive form, was also the first to exploit its resources to the full, in the *Symphonie fantastique* of 1830. This work, besides its technical significance just mentioned, can also be regarded as uniting the characteristics of Romanticism in music: it is both lyrical and dramatic, and, although it makes use of a "story," that use is not to describe the scenes but to connect them; its slow movement is a "nature poem" in the Beethovenian manner; the second, fourth, and fifth movements include "realistic" detail of the most vivid kind; and the opening one is an introspective reverie.

Self-analysis. In this Romantic investigation of the self, some critics have seen little more than excessive ego or, in modern terms, a tiresome narcissism. No doubt certain Romantic works arouse boredom or disgust with hairsplitting analysis. The boredom, however, is often due to the fact that after a hundred years the discoveries have staled. When fresh, they came as a revelation; in the works of the great poets and novelists, in Hazlitt's essays and Jean Paul's fictions, and the irony of Byron's letters or Heine's journalism, the truth has not grown dim or platitudinous.

Desirability of self-analysis

It was in any case desirable that this extensive analysis of the self should be attempted then, for only an age in which individualism was both theoretical and passionate could see the logic of the undertaking and act upon it. The logic was this: given the autonomous and unique individual, a search by himself into his moods, motives, fears, and loves must bring forth data otherwise unobtainable. Add these results together, and one has a repertoire of clues to the inner life of mankind as a whole. For the uniqueness of each individual is bounded by traits he shares with his fellows, and this common element enables the psychologist to connect and organize the reports of the self-searchers. It is on this hypothesis, incidentally, that the demand for originality in art has continued unabated since the Romanticists. Forget the "model," for there is no such thing; avoid conformity; discover your true self, the buried child; be authentic and sincere—these precepts, which still govern art and criticism, are the legacy of Romantic individualism.

Introspection naturally implies an inner life worth looking into, and most Romantic artists brought forth extraordinary findings. They form the groundwork of modern thought. One cannot easily imagine Freud or Joyce, much less the degree of self-consciousness shared by Westerners today, without the deliverances of Blake, Wordsworth, Keats, Leopardi, Stendhal, Constant, Sainte-Beuve, Heine, and innumerable other writers of the early 19th century. And towering above them as the creator of the prototype of Romantic introspection is Goethe with his Faust.

Faust was the figure in which a whole age recognized its mind and soul; and the adjective Faustian, as Spengler's use of it makes clear, still describes tendencies at work in culture today. The principal one, already mentioned, self-consciousness—the identity crisis—remains. The belief, moreover, that movement, activity, is better than repose and that striving is better than achieving is clearly the great postulate of contemporary civilization. Faust himself ends by giving his life to practical works in behalf of his fellow man; however, he sets himself on that path only after a slow and deep analysis of his divided soul, which has been ruled in turn by despair, lust, superstition and the forces of the unconscious, the love of innocence, the conviction of sin and crime, the horrors of hypocrisy and conventional life, the temptations of wealth and power, the disgust with pedantry and established religion, and the yearning for infinite knowledge, in the hopes of attaining by it wisdom and peace. Faust, in short, traverses the whole cosmos, made up of the inner and outer worlds, to find in the act of self-dedication to humanity the justification of his existence.

Early 19th-century social and political thought. The Romantics who studied society through the novel or discoursed about it in essays and pamphlets were no less devoted to this "cause of humanity," but they arrived at politically different conclusions from Goethe's and from one another's. Scott and Disraeli were forerunners of Tory democracy as Burke was of liberal conservatism. Dickens, a passionate humanitarian, stirred the masses with his examples of the law's stupid cruelty, but he proposed no agency of betterment, content to despise Parliament, the law courts, and the complacency of the wealthy. Balzac wrote his huge array of novels as a "social zoology" that was to show what a bloody jungle society becomes without the church and the monarchy to restrain human passions.

The cause of humanity

Stendhal noted the same reality but was more concerned with the free play of individual genius; he resigned himself to the social struggle, provided not too many stupid individuals ran the inevitably heavy-handed regimes. Freedom might be found by the happy few through the loopholes of a mixed government such as England's, whereas in the ostensibly free United States there was no protection against social pressure and no likelihood of genius in art or in politics.

The great authority on American democracy was Tocqueville, whose astonishing survey in two volumes contained many true predictions and is still packed with useful lessons. Tocqueville confirmed Stendhal's low estimate of freedom of thought in America, but he foresaw in the United States the first example of a type of democracy that would surely overtake the Western world. He found in such a future many good things and many defects; he predicted a day when slavery would threaten disaster to America; he foretold what kind of poetry a democracy would produce and delineated the art of Walt Whitman; he apprehended the complication of laws and the declining quality of justice; but he was reconciled to what must be.

Postrevolutionary thinking. What lay behind all 19th-century writings on politics and society was the shadow of the French Revolution. In the 1790s the revolution had aroused Burke to write his famous *Reflections* and Joseph de Maistre his *Considérations sur la France.* They differed on many points, but what both saw, like their successors, was that revolution was self-perpetuating. There is no way to stop it because liberty and equality can be endlessly claimed by group after group that feels deprived or degraded. And the idea that these principles are universally applicable removes any braking power that national tradition or circumstance might afford.

Proof that the revolution marched on, slow or fast, could be read (as it still can be) in every issue of the daily paper since 1789. In the early 19th century the greatest pressure came from the liberals, whether students, bankers, manufacturers, or workmen enlisted in their cause. They wanted

written constitutions, an extension of the suffrage, civil rights, a free-market economy, and from time to time wars of national liberation or aggrandizement in the name of cultural and linguistic unity. For example, all the intellect of western Europe sided with Greece in the 1820s when it began its war of emancipation from Turkey. Byron himself died at Missolonghi while helping the Greeks. Poets wrote odes that musicians set to music, and painters painted scenes of war. Between this liberalism and the nationalism that sought freedom from foreign rule the line could not be clearly drawn. In Italy, Germany, Poland, Russia, Spain, Portugal, and South America, revolt in the name of liberty was endemic until the middle of the century. Only England escaped by a timely reform of Parliament in 1832, but it averted revolution only by a hair's breadth, after protracted threats of civil war and many violent incidents expressing the same animus as elsewhere.

Industrialization

Meanwhile, the first disturbances resulting from machine industry—sabotage, strikes, and conspiracies (for trade unions were generally held illegal)—reinforced the revolutionary momentum, not only in fact but also in theory. As early as 1810 the business cycle, the doctrine of the exploitation of the worker, and the degradation of life in industrial societies had been noted and discussed. By 1825 the writings of the Count de Saint-Simon, which proposed a reorganization of society to cure these evils, had won adherents; by 1830 the Saint-Simonians were an acknowledged party with sympathizers abroad, and by 1832 the words socialism and socialist were in use.

The Saint-Simonian doctrine proposed a benevolent dictatorship of industrialists and scientists to remove the inequities of the free-for-all liberal system. Other reformers, such as the practical Robert Owen, who organized successful communities in Scotland and the United States, depended on a strong leader using ad hoc methods. Still others, such as Leroux and Cabet, were communists of divergent kinds seeking to carry out elaborate blueprints of the perfect state. Proudhon denounced the state, as such, and all private property. As a philosophical anarchist, he wished to substitute free association and contract for all legal compulsions. In England, the school of Bentham and Mill—utilitarians or philosophical radicals—attacked existing institutions in the name of the greatest good of the greatest number, and by their arguments they succeeded in reforming the top-heavy legal system. Without doctrine but moved by a similar sense of wrong, Thomas Carlyle fought the utilitarians for their materialistic expediency and himself sought light on the common problem by pondering the lessons of the French Revolution and publishing in 1837 what is still the greatest account of its catastrophic course. Later, Carlyle gave in *Past and Present* a suggestive picture of what he deemed a true community: quasi-medieval, based on the Faustian joy of work, and relying for its cohesion on its leader's genius and strength of soul.

In the Germanies, repeated outbreaks changed little the system imposed from Vienna by Metternich—censorship, spying on students and intellectuals, repression of group activities at the first sign of political or social advocacy. This drove original thought underground or abroad in the persons of refugees such as the poet Heine and later Karl Marx. At home, the prevailing mood was despair. Max Stirner in his book *The Ego and His Own* (1845) recommended, instead of social reform, a ruthless individualism that should seek satisfaction by any means and at whatever risk. A small group of other individualists, Die Freien ("The Free"), found that satisfaction of the ego through total disillusion and radical repudiation: nothing is true or good—the state is a monster, society sheer hypocrisy, religion a fraud, for God is dead (1840).

Elsewhere the struggle went on, taking shape as reform or revolt as occasion arose. In Italy and France, secret societies carried on propaganda for programs that might be liberal, nationalist, or socialist, but all revolutionary. One irony about the socialists is that the tag that has clung to them is utopian. It suggests purely theoretical notions, whereas the historical fact is that a great many were tried out in practice, and some lasted for a considerable time. As in Carlyle's book, the force of character of one man (Owen was a striking example) usually proved to be the efficient cause of success. Throughout this social theorizing, whatever the means or ends proposed, two assumptions hold: one is that individuals have a duty to change European society, to purge it of its evils; the other is that individuals can change society—they need only come together and decide what form the change shall take. These axioms by themselves, without the memory of 1789, were enough to keep alive in European culture the hope and the threat of continuing revolution.

The principle of evolution. Yet it should not be imagined that revolution by force or radical remodeling inspired every thinking European. Even if liberals and reactionaries were still ready to take to the barricades to achieve their ends, the conservatives were not, except in self-defense. The conservative philosophy, stemming from Burke and reinforced by modern historical studies, maintained the contrary principle of evolution. Evolution indeed swayed as many 19th-century minds as its rival, and it was sometimes the same minds.

Evolution was the belief that lasting and beneficial change comes about by slow and small degrees. It is often imperceptible and therefore congenial to human habits. It breaks no heads and spills no blood; it is natural, organic. The idea of evolution is patterned on biology—the slow growth and decay of living things. More than that, evolution in the zoological sense of "descent with modification" had been a recognized speculation among men of science since 1750, when Buffon included it in his *Histoire naturelle*. Lamarck had elaborated the idea at the turn of the 18th century, while Erasmus Darwin, the grandfather of Charles, had by 1796 worked out for himself a compendious theory of similar import. In 1830–33 the geologist Lyell, setting forth the corresponding notion that changes in the Earth take place through the operation of constant and not cataclysmic causes, devoted a chapter to Lamarckian biology—to the evolution of species by imperceptible steps.

Revival of interest in history

As if these teachings were not enough to implant a form of thought, the revival of interest in history made easy and obvious the transition from the world of nature to that of man. It seemed logical to think of both as evolutions and even to liken the state to an organism. Certainly the student of institutions finds them steadily and profoundly altered by minute incidents and variations. Compared to these causes, the violent breaks made by war and revolution seem more superficial and less permanent.

The evolutionary scheme encouraged several other beliefs while also furnishing fresh arguments and convenient principles. Anyone who had inherited from the previous era a faith in progress could now attach it to this new motive power, evolution. Anyone who wished to classify nations or institutions by rank could place them as he thought proper on an evolutionary scale. Anyone who resisted change or wished to speed it up could be admonished with the aid of some evolutionary yardstick. Finally, anyone who intended to write a work of history or propaganda found the organizing principle ready-made. In the first half of the 19th century, every subject of interest, from costume to the criminal law, was presented in innumerable studies as proceeding majestically at an evolutionary pace.

Another way of stating the influence of this great idea is to say that the mind of Europe had experienced the "biological revolution." Whereas in the 17th century Newtonian physics and its description of the cosmos had imposed the model of mechanics and mathematics, what impressed itself on the 19th century as the universal pattern was the living organism—change and variety as against fixity and regularity. The logic of preferring "biology" to "mechanics" in an age of individualism, of realism about concrete particulars, and of passionate imagination and introspection need only be stated to be evident.

Science. This is not to say that the science of physics stood still during the Romanticist period. It was the time when the conservation of energy was established and the mechanical equivalent of heat demonstrated. There also prevailed the "physical" pseudo-science of phrenology, which professed to relate individual attributes to bumps

and hollows in the skull and which led to the physical anthropology that defined 3, 10, 20, and 100 different races of man by the end of the century. Still, the 19th was more emphatically the century that furnished the theory of the cell (Schleiden and Schwann, 1838–39), which led ultimately to the notion of microscopic creatures responsible for putrefaction and disease and, later still, to cytology and genetics.

It is noteworthy, too, that the 19th century saw the establishment of chemistry on the Daltonian hypothesis of the atom, but it was coloured by the "biological" notion of elective affinities to explain compounds. Goethe, who was an early evolutionist and the scientific expositor of the metamorphosis of plants, called his last novel of human love *Elective Affinities*.

Poetic ideals versus science

On the surface the poetic mind of the age seemed hostile to both science and technology. Wordsworth looks like an enemy of science when he says: "We murder to dissect" and deprecates the man who is willing to "peep and botanize upon his mother's grave." Yet reflection shows that the animus here is not so much against science in general as for the science of life and the reality of human thought and feeling. To understand this temper of the times one must remember how uncertain the intellectual status of physical science still was. Eighteenth-century philosophy had ended in materialism and skepticism. Some writers, such as d'Holbach, had reduced all phenomena to the interaction of hard and unfeeling particles; others, such as Hume, had "proved" that man can know nothing beyond his impressions and therefore can have no certainty about the truth of cause and effect, on which scientific statements depend. The Romanticist generations could neither agree that life was a concourse of unfeeling atoms nor trust the physicists' assertions based on a law of causation that the most acute thinkers had discredited.

Such were the iron constraints within which the famous "crises of the soul" and conversions to religions new or old took place in the 1820s and '30s. Carlyle, Mill, Lamennais, and many others described these crises in famous autobiographical works. The choice seemed to be between a blind and meaningless universe and human life conceived as a brief, pointless exception to the mechanical play of forces. Even if the latter scheme "explained," it was vulnerable to Hume's irrefutable doubts.

Early 19th-century philosophy. What enabled 19th-century culture to pursue the scientific quest and regain confidence in spiritual truth was the work of the German idealist philosophers, beginning with Immanuel Kant.

Kant. Kant took up Hume's challenge and showed that, although we may never know "things as they are," we can know truthfully and reliably the data of experience. The reason for this certitude is that the mind imposes its categories of time and space and causation on the flowing stream and gives it shape. Science, therefore, is not a guess, nor is human knowledge a dream. Both are solid and verifiable. Indeed, certainty, according to Kant, extends as far as morals and aesthetics. The essence of morals is the commandment not to perform any act that one would not want to become a precedent for all human action and always to consider an individual as an end in himself, not as the instrument of another's purpose. The fusion in Kant of ideas stemming from Rousseau and the Enlightenment with ideas fitting the needs of the coming century (Kant died in 1804) made him the fountainhead of European philosophy for 50 years.

Kant's disciples. His disciples—Fichte, Hegel, Schopenhauer—twisted or amplified his teachings. Coleridge in England and Victor Cousin in France adapted to home use what seemed fitting. The school as a whole was known as German idealism because it relied on the distinction between the thinking subject and the perceived object; "idea" and "thing" were unlike, but idea (or the mind) played a role in shaping the reality of things, from which derived all stability and regularity in the universe.

German idealism

Stability was desirable as a guarantor of natural science, but in the social world it was obviously contradicted by events, especially by those since the French Revolution. By 1840 many historians had told the story of the past 50 years, and the lesson they drew from it was almost uniformly that of pessimism. Deprived of Providence and the explanation it used to supply by its "mysterious workings," history seemed neither morally rational nor humanly tolerable.

The German philosopher Hegel, however, drew a different conclusion. Coming after Kant and having witnessed Napoleon's victory at Jena in 1806, he conceived the world as ruled by a new logic, no longer a logic of things static but of things in movement. He saw the forces of history in perpetual battle. Neither side wins, but the upshot of their struggle is an amalgam of their rival intentions. Hegel called the pros and the cons and their survivors thesis, antithesis, and synthesis. Human affairs are ever in dialectic (dialoguing) progression. At times a "world-historical figure" (Luther, Napoleon) embodies the aspirations of the masses and gives them effect through war, revolution, or religious reformation. Yet throughout the succession of events, what is taking place is the unfolding of Spirit or Idea taking on itself the concrete forms of the real. Hegel's was another version of evolution and progress, for he foretold the extension of liberty to all men as the fulfillment of history. It is interesting to note that until 1848 or 1850 Hegel was generally considered a dangerous revolutionary, a believer in an irresistible progress that mankind must earn by blood and battle. Karl Marx, as a younger Hegelian, was to carry out Hegel's unspoken promise on a different base.

Other branches of the all-powerful German philosophy deserve attention but can be spoken of only as they relate to high Romantic themes. Fichte's modification of Kant made the ego the "creator" of the world, an extreme extension or generalization of individualism. At the other extreme, but more in tune with contemporary science and art, Schelling made nature the source of all energy, from which individual consciousness takes off to become the observer of the universe. Nature is a work of art and man is, so to say, its critic, and because human consciousness results from an act of self-limitation, it perceives moral duty and feels the need to worship.

Religion and its alternatives. That need made itself felt ecumenically throughout Europe from the beginning of the 19th century. It had indeed been prepared by the writings of Rousseau as early as 1762 and in England by the even earlier preaching of John and Charles Wesley, the founders of Methodism. The surviving atheism and materialism of the 18th-century philosophes was in truth a greater stimulus to the religious revival of the early 19th century than anything the French Revolution had done, briefly, to replace the established religions. When in the 1800s the Roman Catholic writings of Chateaubriand and Lamennais in France, the neo-Catholic Tractarian movement in England, and the writings of Schleiermacher and his followers in Germany began to take effect, their success was due to the same conditions that made Romanticist art, German idealism, and all the "biological" analogies succeed: the great thirst caused by dry abstractions in the Age of Reason needed quenching. Religious fervour, artistic passion, and "gothic" systems of philosophy filled a void created by the previous simple and mechanical formulas.

The political consequences of the religious revivals

The religious revivals, Catholic or Protestant, also aimed at political ends. Their participants feared the continuation in the 19th century of secularism and wholly material plans. In every country the liberals proposed to set up in the name of tolerance ("indifference," said the Christian believers) governments that would serve exclusively practical (indeed commercial) interests. Church and state were to be separated, education was to be secular, which would really mean antireligious. National traditions would be broken, forgotten, and youth would grow into "economic man," Benthamite utilitarian man, with no intuition of unseen realities, no sensitivity to art or nature, no humility, and no inbred morals or sanction for their dictates.

Scientific positivism. This desire for renewed faith and passion, however, found alternative goals. One was scientific positivism; the other was the cult of art. The name positivism is the creation of Auguste Comte, a French thinker of a mathematical cast of mind who in 1824 began to supply a philosophy of the natural sciences opposed to all metaphysics. Science, according to Comte, deliv-

ers unshakable truth by limiting itself to the statement of relations among phenomena. It does not explain but describes—and that is all mankind needs to know. From the physical sciences rise the social and mental sciences in regular gradation (Comte coined the word sociology), and from these man will learn, in time, how to live in society.

Having elaborated this austere system, Comte discovered the softer emotions through a woman's love, and he amended his scheme to provide a "religion of humanity" with the worship of secular saints, under a political arrangement that the sympathetic Mill nonetheless described as "the government of a beleaguered town." Comte did not attract many orthodox disciples, but the influence of his positivism was very great down to recent times. Not alone in Europe but also in South America it formed a certain type of mind that survives to this day among some scientists and many engineers.

The cult of art. The second "religious" alternative, the cult of art, has had even greater potency, being at the present time the main outlet for spirituality among Western intellectuals. In the Romantic period this fervour was allied with the love of nature and the idolatrous admiration of the man of genius, beginning with Napoleon. A writer as sober as Scott, a thinker as cogent as Hegel, and an artist as skeptical as Berlioz could all say that to them art and its masters were a religion; and they were not alone. At the death of Goethe in 1832, Heine inveighed against the great man's followers who made art the only reality. In the second and third Romantic generations, born about 1820, the religion of art grew still more pronounced and took on an antisocial tone that became more and more emphatic as time passed. "Art for art's sake" ended by signifying, among other things, "art the judge of society and the state." This doctrine was expounded in full detail by the Romantic poet Gautier as early as 1835 in the preface to his entertaining and sexually daring novel *Mademoiselle de Maupin.* In those pages the familiar argument against bourgeois philistinism, against practical utility, against the prevailing dullness, ugliness, and wrongness of daily life was set forth with much wit and that spirit of defiance which one usually thinks of as belonging to the 1890s or the present day. Its occurrence then is but another proof that Romanticism was the comprehensive culture from which later styles, thoughts, and isms have sprung.

"Art for art's sake"

The middle 19th century. During the half century when Romanticism was deploying its talents and ideas, the political minds inside or outside Romanticist culture were engaged in the effort to settle—each party or group or theory in its own way—the legacy of 1789. There were at least half a dozen great issues claiming attention and arousing passion. One was the fulfillment of the revolutionary promise to give all Europe political liberty—the vote for all, a free press, a parliament, and a written constitution. Between 1815 and 1848 many outbreaks occurred for this cause. Steadily successful in France and England, they were put down in central and eastern Europe under the repressive system of Metternich.

A second issue was the maintenance of the territorial arrangements of the treaties that closed the Napoleonic Wars at the Congress of Vienna in 1815. Metternich's spies and generals also worked to keep this part of the post-Napoleonic world intact; that is, the boundaries that often linked (or separated) national groups in order to buttress dynastic interests. Except in Belgium, the surge of national, as distinct from liberal, aspirations throughout Europe was unsuccessful in the 1830s. Defeats only strengthened resolve, particularly in Germany and Italy, where the repeated invasions by the French during the revolutionary period had led to reforms and stimulated alike royal and popular ambitions. In these two regions, liberalism and nationalism merged into one unceasing agitation that involved not merely the politically militant but the intellectual elite. Poets and musicians, students and lawyers joined with journalists, artisans, and good bourgeois in open or secret societies working for independence: they were all patriots and all more or less imbued with a Romanticist regard for the people as the originator of the living culture, which the nation was to enshrine and protect.

Merger of liberalism and nationalism

To be sure, this patriotic union of hearts did not mean agreement on the details of future political states, and the same disunion existed to the west, in England and France, where liberals, only half satisfied by the compromises of 1830 and 1832, felt the push of new radical demands from the socialists, communists, and anarchists. Reinforcing these pressures was the unrest caused by industrialization—the workingman's claims on society, expressed in strikes, trade unions, or (in England) the Chartists' demanding "the Charter" of a fully democratic Parliament. This cluster of parties agitated for a change that went well beyond what the advanced liberals themselves had not yet won. Add to these movements those that purposed to stand still or to restore former systems of monarchy, religion, or aristocracy, and it is not hard to understand why the great revolutionary furnace of 1848–52 was a catastrophe for European culture. The four years of war, exile, deportation, betrayals, coups d'état, and summary executions shattered not only lives and regimes but also the heart and will of the survivors. The hoped-for evolution of each nation and would-be nation, as well as the desire for a Europe at peace, was broken and, with all other hopes and imaginings, rendered ridiculous. The search began for new ways to achieve, on the one side, stability and, on the opposite, the final desperate revolution that would usher in the good society.

For although they seemed decisive, the battles of '48 and after did not, in fact, test the worth of any one idea. Nationalism won and lost in different parts of Europe. Liberalism gained in Italy and Switzerland, but was set back in Germany and France. English Chartism seemed to collapse, yet its demands began to be carried out. The socialist experiment in France (Louis Blanc's national workshops) also seemed discredited; yet the ensuing regime of Napoleon III made attempts, however clumsy, to deal with poverty by welfare methods. Repression had shifted people and territories—Metternich was gone from Austria—but Germany and France were not on that account flourishing under liberty, equality, and fraternity. There was peace, but war was imminent; and subversive groups continued to plot and frighten the bourgeois, to try to kill royal heads of state, while machine industry and the resulting urbanization contributed their gains at the cost of the now familiar miseries and sordor.

In these circumstances the mind of Europe suffered an eclipse, followed by a protracted mood of despondency. Many established or emerging artists and thinkers had been killed or torn from their homes or deprived of their livelihood: Wagner fleeing Dresden, where he conducted the opera; Chopin and Berlioz at loose ends in London, because in Paris music other than opera was moribund; Verdi going back to Milan with high patriotic hopes and returning to Paris in a few months, utterly disillusioned; and Hugo in exile in Belgium and later in Guernsey—all typify the vicissitudes in which men of reputation found themselves in mid-career. For the young and unknown, such as the poet Baudelaire or the English painters who formed the Pre-Raphaelite Brotherhood, it was no time to invite the public to admire boldness and accept innovation. Critics and public alike were all nerves and hostility to subversion. To read Flaubert's masterpiece, *Sentimental Education* (1869), is to understand the atmosphere in which the first phase of Romanticism ended and its ramified sequels came into being.

Mood of despondency

Realism and *Realpolitik.* The dominant feeling was that high hopes had perished in gunfire, and this realization bred the thought that hope itself was an error. Any new effort must therefore stay close to the possible, the "real." Realism with a capital R and *Realpolitik* together sink their roots in a distrust of man's imagination. This grim caution born of harsh experience coincided with a sense of fatigue that made Romanticist work seem like the foolishness of youth.

The appropriate cultural note must no longer be the infinite or heroic or colourful but rather their opposites. If the commonly accepted term Realism for this reaction of the 1850s is used, it must be with these presuppositions in mind. For the Romantic passion for the particular and exact was a realism, too; it was what Dr. Johnson much

earlier had called "vehement real life." The Realism of the disillusioned '50s dropped the vehement, the passionate and, in order to run no risk of further disillusion, limited what it called real to what could be readily seen and felt: the commonplace, the normal, the workaday, and often the sordid.

Limitation of "real"

In the same spirit *Realpolitik* rejected principles. The word did not mean "real" in the English sense; in German it connotes "things"—hence a politics of adaptation to existing facts, pursuing plain objects, admitting no obligation to ideals. In this light we can understand the unexpected epithet "scientific" that Marx and his followers bestowed on their brand of socialism. It was a science not merely because it was presumably based on the laws of history but even more because in its view the advent of the socialist state was to result from the interaction of things (classes, means of production, and economic necessity) and not, as in earlier socialism, from the will (that is, the imaginative efforts of thinking men). The "objective" appearance given to the new politics of things, socialist or other, generated that tough, no-nonsense atmosphere, which people then wanted as a source of reassurance in all their dealings.

Scientific materialism. This search for certainty went with a swinging back of the pendulum in science itself from the vitalism of the previous period to the materialism of the mid-century. German philosophers derided idealism and taught the equivalence of consciousness and chemistry: "without phosphorus, no thinking." The machine once more became the great model of thought and analogy—and nowhere more vividly and persuasively than in biology, where Darwin's advocacy of natural selection won the day because it provided a mechanical means for the march of evolution. The struggle for life (Spencer's phrase of 1850, adopted by Darwin in the subtitle of his book) obviously had the requisite "toughness" to convince and, like *Realpolitik*, it followed no principle—whoever survived survived. That Darwin to the very last included other factors in his theory of evolution—Lamarckian "use and disuse" as well as direct environmental forces—carried no weight with a generation bent upon machine certainty. These secondary explanations were ignored, in the usual way of cultural single-mindedness, and for 30 years after the publication of the *Origin of Species* in 1859, an orthodoxy of universal mechanism reigned over all departments of thought.

It prevented the recognition of Mendel's work on genetics; it put religious, philosophical, and ethical thought on the defensive—only what was "positive" (*i.e.,* material) held a presumption of being real and true. The same reasoning produced a school of social Darwinists who saw war between nations and economic struggle among individuals as beneficent competition leading to the survival of "favoured races"—another phrase from Darwin's subtitle. And by a final twist of logic, the creed of materialism reinforced the moral gloom of the period by casting doubt on both the permanence and the validity of all that was being redefined as "really real." For on the one side, the second law of thermodynamics guaranteed the cooling of the Sun and the pulverization of the cosmos into cold and motionless bits of matter; and, on the other, orthodox "machine-ism" brought its leading prophets, Huxley and Tyndall, to consider people and animals as automatons moved as helplessly as atoms and planets. Consciousness is an epiphenomenon—in plain words, an illusion—precisely as in Karl Marx consciousness and culture are illusions floating above the reality of economic relations.

The "really real"

Victorian morality. To be sure, not everybody in Europe believed or worried about these affirmations. And although ideas long debated do in the end filter down to the least intellectual layers of the population, the time and place of triumph for a philosophy are limited by this cultural lag—a fortunate delay, without which whole societies might collapse soon after the publication of a single book. What kept mid-19th-century civilization whole was a subdued faith in the reality of all the things Realism and materialistic science denied: religious belief, civic and social habits, the dogma of moral responsibility, and the hope that consciousness and will did exist.

The sum of these invisible forces is conveniently known as the Victorian ethos or Victorian morality, a formula applicable to the Continent as well as Britain and one whose meaning antedates not only the mid-century revolutions but also the accession of Queen Victoria in 1837. Like Romanticism, this powerful moralism had its roots in the late 18th century—in Wesleyan Methodism and the Evangelical movement, in Rousseau, Schiller, and Kant. Its earnestness was of popular origin; it was antiaristocratic in manners, and it sought the good and the true in a simple, direct, unhesitating way. Perceiving with warm feeling that all men are brothers under God, the moral man saw that slavery was wrong; and having so concluded, he proceeded to have it abolished by act of Parliament (Britain, 1833).

Such fervent convictions when widely shared exert tremendous power, and this concentration of belief and emotion made Victorian morality long impregnable. As Chesterton said of the Victorian painter Watts:

> He has the one great certainty which marks off all the great Victorians from those who have come after them: he may not be certain that he is successful, or certain that he is great, or certain that he is good, or certain that he is capable: but he is certain that he is right.

The sense of rightness generated a sense of power, which the Victorians applied to the monumental task of keeping order in a postrevolutionary society.

Partly by taking thought and partly by instinct, they perceived that the drive to revolution and the sexual urge were somehow linked. Therefore they repressed sexuality; that is, repressed it in themselves and their literature, while containing it within specified limits in society. Further, they knew that the successful working of the vast industrial machine required a strict, inhuman discipline. The idolatry of respectability was the answer to natural waywardness. To pay one's bills, wear dark clothes, stifle individual fancy, go to church regularly, and turn aggression upon oneself in the form of worry about salvation became the approved common modes of pursuing the pilgrimage of life.

Idolatry of respectability

It could not be expected that everybody would or could conform. From its beginning to the end, the Victorian age numbered a galaxy of dissenters and critics who scorned the conformity, called the religion a sham, and viewed respectability as mere hypocrisy. Yet the front held, and the massed forces behind it were at their strongest after the multiplied assaults of 1848.

Nothing gives a better idea of the astonishing moral structure called Victorianism than the development of the London Metropolitan Police, begun under Sir Robert Peel in 1829. A lawyer and a former captain who had fought in the Peninsular War were the first joint commissioners and creators of the force. At first they had to weed out the drunks and the bullies who had been the main types of recruit in earlier attempts at policing cities. At first, too, the people both ridiculed and fought with the new police. Gradually, the "peelers" came to be trusted; they remained unarmed regardless of circumstances; they learned to handle rioters without shedding blood; and in the putting down of crime they finally enlisted the public on their side. For something less than a century this unique relationship lasted, in which "law-abiding" and "police" were terms of respect—correlative terms, since the peelers (later "bobbies") could not have become what they were without the self-discipline and moral cohesion of the "respectable."

The upheavals of the mid-century, cultural as well as political, put Victorianism to a severe test, for after wars and civil disorders laxity is natural, and ensuing despair induces a reckless fatalism. There was cause indeed for apprehension. When the Great Exhibition of 1851 was planned on a scale theretofore unattempted, many expressed the fear that to allow tens of thousands from all over Europe to come together under the Crystal Palace was to invite massive riots. Ministers and heads of state would be assassinated. In the event, no protracted assembly of common people and their leaders was ever so quiet and orderly. The moral machinery worked as efficiently as that which was on display under the glass dome.

The advance of democracy. Yet, while a stringent

moralism held in check endemic subversion and anarchy, Darwinism and the machine analogy stimulated endless forms of self-consciousness. If man could fashion and continually improve these engines, perhaps he could also engineer an improved society. Because evolution was at last "proved," thanks to Darwin, perhaps it also gave warrant for social and political progress by gradual steps. Spencer's all-inclusive philosophy, likened then to Aristotle's, foresaw an inevitable movement from the simple and undifferentiated to the complex and specialized—as in modern life. Clearly, whether automatons or not, people kept thinking and having purposes; and among evolutionists and scientific socialists alike, thought and purpose included the hastening by voluntary action of what was sure to come by force of natural laws. These and other desires acting in the light of Realism and taking shape in the increasing organization of the toiling masses brought Europe to accept democracy as inevitable.

Evolution as a warrant for social and political progress

The word democracy is used here in a cultural sense. It does not imply a set of political institutions so much as the signs and the agencies that herald the coming populist state of our day: for example, the extension of the franchise, in parliamentary or plebiscite form; the secret ballot; the legalization of trade unions; the rise of a Roman Catholic social movement; the passage of education acts providing free, public, and compulsory schooling; the formulation of the paternalistic Tory democracy as a cure for the evils of free-for-all economic liberalism; the beginnings of welfare legislation (in France under Napoleon III, in Germany under Bismarck); the secularization of life by state action, by the prestige of science, and also by the liberal movements within the churches themselves; and finally, after a decade or so of public education, the great extension and popularization of the press. At the passage of the Reform Act of 1867 in Britain, which gave the vote to urban workingmen, Robert Lowe had said, "Now we must educate our masters." In a parliamentary system the means to that education cannot be the schools alone. The adult "common man" must continually be informed and appealed to for his own satisfaction as well as for coherent policy in government. The instrument for this purpose was the new journalism. The quarterlies of the early 19th century gave way to the monthlies in the 1860s and they in turn to the weeklies, while the daily papers, costing now but a penny and simplifying all they touched, began to reach the millions.

Realism in the arts and philosophy. In the period of so-called Realism, the arts and philosophy as usual supplied—at least for the educated elite—form and substance to the prevailing fears and desires. The mood of soberness and objectivity was alone acceptable, and what art presented to the public confirmed the reasonableness of the mood.

Literature. This interaction accounts for such things as the marked change of tone in Dickens' novels that occurs between *David Copperfield* (1850) and *Bleak House* (1853). The temper expressed in most concentrated form the very next year in *Hard Times* now dominates Dickens' mind and works to the end: life is a dreary sort of underworld; happy endings are artificially contrived and not to be believed.

The same mood explains why Gustave Flaubert's *Madame Bovary* (1857), which ranks today as the realistic novel par excellence and is on all counts grim enough in its rendering of boredom and vulgar misery, was judged "too artistic" by some contemporary critics, not close enough to the most common of realities, that of common speech. At the same time, the sought-for effect could be achieved in poetry by juxtaposing the ideal, or simply the decent, with the dreary and disgusting, especially the occurrence of these in the now hateful urban life. This is what Baudelaire did in a volume of poems called *The Flowers of Evil* (1857). The attack this time came not from critics who found the work insufficiently real, but from the "respectable" readers who found it indecent and immoral.

Yet the evolution of Flaubert's mind remains instructive for an understanding of Realism as a literary creed. Flaubert had begun by writing a highly coloured, imaginative story on *The Temptation of Saint Anthony* (1848), which the author's friends advised him to burn, tone down, or rewrite. Flaubert put it aside and began the novel that became *Madame Bovary.* Its setting was the provincial world around him, not the Egyptian desert; the characters were of the most ordinary type, not an improbable Christian ascetic haunted by visions. Yet, even in the working out of his plain tale, Flaubert had to subdue his lyrical Romantic genius to the discipline he had adopted. The description of a rainstorm, for instance, had to be done over and over again so that it would not stand out and be "interesting" by virtue of the observer's mind. It had to be made ordinary and the observer kept outside, just as in science. *Madame Bovary,* begun as a magazine serial, was soon censored by the editor and then prosecuted as immoral by the state. For Flaubert's Realism had gone so far as to portray in no flattering colours the dreary lives and motives of average provincials of both sexes, and the picture violated the rules of the indispensable moralism. What is more, the fate of Flaubert's unhappy heroine symbolized what had happened to the more daring and poetic-glorious time before 1848: as Flaubert said, Emma Bovary was himself.

The significance of *Madame Bovary*

His novel is thus simultaneously a model and a critique of the new genre—a critique, too, of the state of Europe that produced it. Many other writers between 1850 and 1890 pursued matter-of-factness without this ulterior effect and rendered the details of middling life with such impassiveness and fidelity that to this day many use "realistic" as a synonym for dreary or sordid and regard "the novel" as a reliable historical source. On the precise definition of Realism, George Gissing gave, through a character in one of his own novels, a brilliant commentary: the character is at work on a novel which shall be so true to the dullness of daily life that no one will be able to read it.

Painting and sculpture. The term Realism applies no less to the plastic arts than to literature, but in painting and sculpture it proved difficult to give form overnight to the change of attitude just noticed in literature and political life. The transition between the passionate poetry and drama of Géricault and Delacroix and the Realism of Courbet and Manet was gradual. It came by way of the "open-air" school of Barbizon, whose landscapes seemed arid (at least to the classically trained academic painters of the day) and pointless in the sense that they depicted the commonplace. Still, when the full shock of Realism inflicted by the works of Courbet and Manet occurred, it was severe: here were coarseness and violence in manner and subject. Courbet's backgrounds are thick and his people drab; Manet's nude "Olympia" is no goddess nor even a beautiful woman; she is a prostitute, and her name seems like a piece of irony. The portrait of his parents is a painful representation of simple poverty unrelieved by any glow of spirit or intelligence—yet the work itself is beautiful: such was, throughout, the aim and achievement of Realism.

The gradual transition to Realism in painting

In England, by an historical accident, pictorial realism was embodied in subjects that seem far removed from the commonplace. The school that took up the challenge against academic painting and modified the vision of Constable and Turner called itself Pre-Raphaelite. Its members were Holman Hunt, John Millais, and Dante Gabriel Rossetti, and the name they took for their "brotherhood" expressed their resolve to paint like the masters who came before the imitators of Raphael. It is necessary to put it in this clumsy way in order to make clear that Raphael himself was not being condemned, but only his academic followers who introduced "unreality."

To be a Pre-Raphaelite was to see the world with a sharp eye and an undistorting mind and to render it with intense application to solidity of form, bright colour, and natural pose and grouping. All this was to be understood from the motto "Death to Slosh!" In order to make the new virtues vividly clear and also because the Pre-Raphaelites were reared on great literature, their subjects tended to draw upon legend, or Dante, or the New Testament. It was the conception and treatment that constituted the innovation. Everybody could see it, because it went against the habit of "pretty-pretty" illustration. In fact the nominal subject dropped out of sight in the startled response to form and colour. Paradoxically, then, the commonplace subjects of

the French Realists and the legendary ones of the English Pre-Raphaelites were alike insignificant when compared with the effort to re-create by art the texture and "feel" of actuality—and nothing more. Such was precisely the goal Flaubert pursued and reached in *Madame Bovary.* His final version of the St. Anthony story (1874) made the same point with a legendary subject, like the Pre-Raphaelites.

Popular art. It hardly needs to be added that this conscious purpose of high art could interest but a relatively small portion of the public and that, for the growing mass of readers of fiction and viewers of art, other kinds of satisfaction were necessary. The ordinary three-volume novel from the lending library and the continued serial in the magazine or newspaper supplied the demand by aping, adapting, and diluting not one but half a dozen literary tendencies, old and new. The number of novels produced in all languages in the 19th century has never been estimated, but it surely must be on the order of astronomical magnitudes. And the whole output was realistic in the sense that it professed to impart the real truth about life. It was contemporary in setting and speech, took the form of a history, and taught its readers how other people lived. The pictorial counterpart was the "chromo," the cheap colour lithograph that illustrated either fiction or news stories in forms which, however false they must seem to a critical eye, again gave the illusion of commonplace reality.

Growth of the novel in the 19th century

Music. At first sight, it would seem as if music were a medium in its nature resistant to Realism, but that is to reckon without the obvious use that music has always made of sounds directly associated with life—church bells, hunting horns, military bands, and the like. In an age when Realism was at a premium, the opera would be the form where these and other associations easily found their place. So it was in mid-century Europe, where Meyerbeer and others provided the effects to suit the fussily "real" staging of all plays, musical or not. Clocks, tables, animals, waterfalls, and especially costume could be relied on to be genuine up to the limit of the possible: live bullets for real deaths were shied away from, and real lightning was out of reach.

A genius who is often mistakenly grouped with the Romantics, Richard Wagner, supplied this ultimate deficiency—and by musical means. As critics have pointed out, Wagner's system of leitmotivs, or musical tags that denoted an object, a person, or an idea, was consciously or unconsciously an accommodation of Realist intent to operatic understanding. This is true not simply because the musical notes "wave" up and down as Isolde waves her scarf at Tristan—a trivial enough device of a sort found in many composers; it is also true in the deeper sense, which constitutes Wagner's unique genius, namely that he was able to compose great music that was steadily and precisely denotative of items in the story by repeating and interweaving their assigned musical tags.

Summary. Looking back from the perspective of Modernism, which is characteristic of 20th-century culture, it is clear that its predecessor, Romanticism, did not stop in the middle of the 19th. Rather, it evolved and branched out into the phases known as Realism, Neo-Classicism, Naturalism, and Symbolism. All the tendencies and techniques that gave passing unity to these actions and reactions are found in germ in the original flowering of art and thought that dates from about 1790.

By concentrating on one purpose, by specializing as it were in one affirmation, the succeeding movements after 1848 made their emphatic mark, until the original inspiration was exhausted. It is thus that cultural movements end—in sterile imitation and pointlessness—and thereby earn the scorn of the next generation. This in turn explains why in the decade before World War I one finds, besides a fresh surge of energy and shocking creations, the driving force of anti-Romanticism, anti-Victorianism, anti-everything that was not some form of the new and "Modern."

(J.Ba.)

A MATURING INDUSTRIAL SOCIETY

The "second industrial revolution." As during the previous half century, much of the framework for Europe's history following 1850 was set by rapidly changing social and economic patterns, which extended to virtually the entire continent. In western Europe, shifts were less dramatic than they had been at the onset of the Industrial Revolution, but they posed important challenges to older traditions and to early industrial behaviours alike. In Russia, initial industrialization contributed to literally revolutionary tensions soon after 1900.

The geographic spread of the Industrial Revolution was important in its own right. Germany's industrial output began to surpass that of Britain by the 1870s, particularly in heavy industry. The United States became a major industrial power, competing actively with Europe; American agriculture also began to compete as steamships, canning, and refrigeration altered the terms of international trade in foodstuffs. Russia and Japan, though less vibrant competitors by 1900, entered the lists, while significant industrialization began in parts of Italy, Austria, and Scandinavia. These developments were compatible with increased economic growth in older industrial centres, but they did produce an atmosphere of rivalry and uncertainty even in prosperous years.

Throughout the most advanced industrial zone (from Britain through Germany) the second half of the 19th century was also marked by a new round of technological change. New processes of iron smelting such as that involving the use of the Bessemer converter (invented in 1856) expanded steel production by allowing more automatic introduction of alloys and in general increased the scale of heavy industrial operations. The development of electrical and internal combustion engines allowed transmission of power even outside factory centres. The result was a rise of sweatshop industries that used sewing machines for clothing manufacturing; the spread of powered equipment to artisanal production, on construction sites, in bakeries and other food-processing centres (some of which saw the advent of factories); and the use of powered equipment on the larger agricultural estates and for processes such as cream separation in the dairy industry. In factories themselves, a new round of innovation by the 1890s brought larger looms to the textile industry and automatic processes to shoe manufacture and machine- and shipbuilding (through automatic riveters) that reduced skill requirements and greatly increased per capita production. Technological transformation was virtually universal in industrial societies. Work speeded up still further, semi-skilled operatives became increasingly characteristic, and, on the plus side, production and thus prosperity reached new heights.

Organizational changes matched the "second industrial revolution" in technology. More expensive equipment, plus economies made possible by increasing scale, promoted the formation of larger businesses. All western European countries eased limits on the formation of joint-stock corporations from the 1850s, and the rate of corporate growth was breathtaking by the end of the century. Giant corporations grouped together to influence the terms of trade, particularly in countries such as Germany, where cartels controlled as much as 90 percent of production in the electrical equipment and chemical industries. Big business techniques had a direct impact on labour. Increasingly, engineers set production quotas, displacing not only individual workers but also foremen by introducing time-and-motion procedures designed to maximize efficiency.

Change in business organization

Modifications in social structure. Developments in technology and organization reshaped social structure. A recognizable peasantry continued to exist in western Europe, but it increasingly had to adapt to new methods. In many areas (most notably, The Netherlands and Denmark) a cooperative movement spread to allow peasants to market dairy goods and other specialties to the growing urban areas without abandoning individual landownership. Many peasants began to achieve new levels of education and to adopt innovations such as new crops, better seeds, and fertilizers; they also began to innovate politically, learning to press governments to protect their agricultural interests.

In the cities the working classes continued to expand, and distinctions between artisans and factory workers, though real, began to fade. A new urban class emerged as sales



Europe, 1871–1914.

outlets proliferated and growing managerial bureaucracies (both private and public) created the need for secretaries, bank tellers, and other clerical workers. A lower middle class, composed of salaried personnel who could boast a certain level of education—indeed, whose jobs depended on literacy—and who worked in conditions different from manufacturing labourers, added an important ingredient to European society and politics. Though their material conditions differed little from those of some factory workers, though they too were subject to bosses and to challenging new technologies such as typewriters and cash registers, most white-collar workers shunned association with blue-collar ranks. Big business employers encouraged this separation by setting up separate payment systems and benefit programs, for they were eager to avoid a union of interests that might augment labour unrest.

The separation of "white-collar" and "blue-collar" workers

At the top of European society a new upper class formed as big business took shape, representing a partial amalgam of aristocratic landowners and corporate magnates. This upper class wielded immense political influence, for example, in supporting government armaments buildups that provided markets for heavy industrial goods and jobs for aristocratic military officers.

Along with modifications in social structure came important shifts in popular behaviour, some of them cutting across class lines. As a result of growing production, prosperity increased throughout most of western Europe. Major economic recessions interrupted this prosperity, as factory output could outstrip demand and as investment speculation could, relatedly, outstrip real economic gains. Speculative bank crises and economic downturns occurred in the mid-1850s and particularly in the middle years of both the 1870s and '90s, causing substantial hardship and even wider uncertainty. Nevertheless, the general trend in standards of living for most groups was upward, allowing ordinary people to improve their diets and housing and maintain a small margin for additional purchases. The success of mass newspapers, for example, which reached several million subscribers by the 1890s, depended on the ability to pay as well as on literacy. A bicycle craze, beginning among the middle classes in the 1880s and gradually spreading downward, represented a consumer passion for a more expensive item. Improvement in standards of living was aided by a general reduction in the birth rate, which developed rapidly among urban workers and even peasants. Families increasingly regarded children as an expense, to be weighed against other possibilities, and altered traditional behaviour accordingly. Reduction in the birth rate was achieved in part by sexual abstinence but also by the use of birth control devices, which had been widely available since the vulcanization of rubber in the 1840s, and by illegal abortions. Completing the installation of a new demographic regime was a rapid decline in infant mortality after 1880.

Rising living standards were accompanied by increased leisure time. Workers pressed for a workday of 12, then 10 hours, and shortly after 1900 a few groups began to demand an even shorter period. Scattered vacation days also were introduced, and the "English weekend," which allowed time off on Saturday afternoons as well as Sundays, spread widely. Middle-class groups, for their part, loosened their previous work ethic in order to accommodate a wider range of leisure activities.

The birth of modern leisure

The second half of the 19th century witnessed the birth of modern leisure in western Europe and, to an extent, beyond. Team sports were played in middle-class schools and through a variety of amateur and professional teams. Many sports, such as soccer (football), had originated

in traditional games but now gained standardized rules, increasing specialization among players, and the impassioned record-keeping appropriate to an industrial age. Sports commanded widespread participation among various social groups and served as the basis for extensive commercial operations. Huge stadiums and professional leagues signaled the advent of a new level of spectatorship. While many sports primarily focused on male interests, women began to participate in tennis and entire families in pastimes such as croquet and bicycling.

Leisure options were by no means confined to sports. Mass newspapers emphasized entertaining feature stories rather than politics. Parks and museums open to the public became standard urban features. Train excursions to beaches won wide patronage from factory workers as well as middle-class vacationers. A popular theatre expanded in the cities; British music-hall, typical of the genre, combined song and satire, poking fun at life's tribulations and providing an escapist emphasis on pleasure-seeking. After 1900, similar themes spilled into the new visual technology that soon coalesced into early motion pictures.

The rise of organized labour and mass protests. Mass leisure coexisted interestingly with the final major social development of the later 19th century, the escalating forms of class conflict. Pressed by the rapid pace and often dulling routine of work, antagonized by a faceless corporate management structure seemingly bent on efficiency at all costs, workers in various categories developed more active protest modes in the later 19th century. They were aided by their growing familiarity with basic industrial conditions, which facilitated the formation of relevant demands and made organization more feasible. Legal changes, spreading widely in western Europe after 1870, reduced political barriers to unionization and strikes, though clashes with government forces remained a common part of labour unrest.

Not surprisingly, given the mood of reaction following the failures of the 1848 revolutions, the 1850s constituted a period of relative placidity in labour relations. Skilled workers in Britain formed a conservative craft union movement, known as New Model Unionism, that urged calm negotiation and respectability; a number of durable trade unions were formed as a result, and a minority of workers gained experience in national organization. Miners and factory workers rose in strikes occasionally, signaling a class-based tension with management in many areas, but no consistent pattern developed.

The depression of the 1870s, which brought new hardship and reminded workers of the uncertainty of their lot, encouraged a wider range of agitation, and by the 1890s mass unionism surfaced throughout western Europe. Not only artisans but also factory workers and relatively unskilled groups, such as dockers, showed a growing ability to form national unions that made use of the sheer power of numbers, even in default of special skills, to press for gains. Strike rates increased steadily. In 1892 French workers struck 261 times against 500 companies; most of the efforts remained small and local, and only 50,000 workers were involved. By 1906, the peak French strike year before 1914, 1,309 strikes brought 438,000 workers off the job. British and German strike rates were higher still; in Britain, more than 2,000,000 workers struck between 1909 and 1913. A number of nationwide strikes showed labour's new muscle.

Unionization formed the second prong of the new labour surge. Along with mass unions in individual industries, general federations formed at the national level, such as the British Trades Union Congress and the French and Italian general confederations of labour. Unions provided social and material benefits for members along with their protest action; in many industries they managed to win collective bargaining procedures with employers, though this was far from a uniform pattern in an atmosphere of bitter competition over management rights; and they could influence governmental decisions in the labour area.

The rise of organized labour signaled an unprecedented development in the history of European popular protest. Never before had so many people been formally organized; never before had withdrawal of labour served as the chief protest weapon. Many workers joined a sweeping ideological fervor to their protest. Many were socialists, and a number of trade union movements were tightly linked to the rising socialist parties; this was particularly true in Germany and Austria. In other areas, especially France and Italy, an alternative syndicalist ideology won many adherents in the union movement; syndicalists urged that direct action through strikes should topple governments and usher in a new age in which organizations of workers would control production. Against these varied revolutionary currents, many workers saw in unions and strikes primarily a means to compensate for changes in their work environment, through higher pay (as a reward for less pleasant labour) and shorter hours. Even here, there was an ability to seek new ends rather than appealing to past standards. Overall, pragmatism battled with ideology in most labour movements, and in point of fact none of the large organizations aimed primarily at revolution.

Syndicalism

Labour unrest was not the only form of protest in the later 19th century. In many continental nations (but not in Britain or Scandinavia), nationalist organizations drew the attention of discontented shopkeepers and others in the lower middle class who felt pressed by new business forms, such as department stores and elaborate managerial bureaucracies, but who were also hostile to socialism and the union movement. Nationalist riots surfaced periodically in many countries around such issues as setbacks in imperialist competition or internal political scandals. Some of the riots and accompanying organizations were also anti-Semitic, holding Jews responsible for big business and socialism alike. France witnessed the most important agitation from the radical right, through organizations like the Action Française; but anti-Semitic political movements also developed in Germany and Austria.

Important women's movements completed the new roster of mass protests. The basic conditions of women did not change greatly in western Europe during the second half of the 19th century, with the significant exception of the rapidly declining birth rate. The steady spread of primary education increased female literacy, bringing it nearly equal to male levels by 1900. A growing minority of middle-class women also entered secondary schools, and by the 1870s a handful reached universities and professional schools. Several separate women's colleges were founded in centres such as Oxford and Cambridge, and, against heavy resistance, a few women became doctors and lawyers. For somewhat larger numbers of women, new jobs in the service sector of the economy, such as telephone operators, primary-school teachers, and nurses, provided opportunities for work before marriage. Gradually some older sectors of employment, such as domestic service, began to decline. Nevertheless, emphasis on a domestic sphere for women changed little. Public schools, while teaching literacy, also taught the importance of household skills and support for a working husband.

These were the circumstances that produced increasingly active feminist movements, sometimes independently and sometimes in association with socialist parties. Feminist leaders sought greater equality under the law, an attack on a double-standard sexuality that advantaged men. Above all, they came to concentrate on winning the vote. Massive petitions in Britain, accompanied by considerable violence after 1900, signaled Europe's most active feminist movement, drawing mainly on middle-class ranks. Feminists in Scandinavia were successful in winning voting rights after 1900. Almost everywhere, feminist pressures added to the new variety of mass protest action.

Conditions in eastern Europe. Social conditions in eastern and southern Europe differed substantially from those of the west, but there were some common elements. Middle- and upper-class women in Russia, for example, surged into new educational and professional opportunities in some numbers. Growing cities and factories produced some trade union activity, on the part of skilled groups such as the printers and metalworkers, that resembled efforts elsewhere.

Rural conditions, however, were vastly different from those in western Europe. Eastern and southern Europe remained dominated by the peasantry, as urbanization,

though rapid, was at a far earlier stage. Peasant conditions were generally poor. Amid growing population pressure, many peasants suffered from a lack of land in areas dominated by large estates. One result was rapid emigration, to the Americas and elsewhere, from Spain, southern Italy, and eastern Europe. Another result was recurrent unrest. Peasants in southern Spain, loosely organized under anarchist banners, rose almost once a decade in the late 19th century, seizing land and burning estate records.

The social and economic situation was most complex in Russia. Stung by the loss of the Crimean War (1854–56) to Britain, France, and the Ottoman Empire, literally in their own backyard, Russian leaders decided on a modernization program. The key ingredient was an end to the rigid manorial system, and in 1861 Alexander II, a reform-minded tsar, issued the Emancipation Manifesto, freeing the serfs. This act sought to produce a freer labour market but also to protect the status of the nobility. As a result, noble landlords retained some of the best land and were paid for the loss of their servile labour; in turn, serfs, though technically in control of most land, owed redemption payments to the state. This arrangement produced important changes in the countryside. Peasants did develop some commercial habits, aided by gradually spreading education and literacy. More and more peasants migrated, temporarily or permanently, to cities, where they swelled the manufacturing labour force and also the ranks of urban poor. Rural unrest continued, however, as peasants resented their taxes and payments and the large estates that remained.

The emancipation of the serfs

From the 1870s the Russian government also launched a program of industrial development, beginning with the construction of a national rail network capped by the Trans-Siberian Railroad. Factory industry was encouraged; much of it was held under foreign ownership, though a native entrepreneurial class emerged. Large factories developed to produce textiles and to process metals. Conditions remained poor, however, and combined with the unfamiliar pace of factory work and rural grievances to spur recurrent worker unrest. Illegal strikes and unions became increasingly prominent after 1900. A minority of urban workers, particularly in St. Petersburg and Moscow, were won to socialist doctrines, and a well-organized Marxist movement arose, its leadership after 1900 increasingly dominated by Vladimir Ilich Lenin, a creative theorist who adapted Marxist theory to the Russian situation and who concentrated single-mindedly on creating the network of underground cells that could foment outright revolution. Russia was embarked on a genuine industrial revolution; with its massive size and resources, it ranked among world leaders in many categories of production by 1900. However, it operated in an exceptionally unstable social and political climate.

THE EMERGENCE OF THE INDUSTRIAL STATE

Political patterns. During the second half of the 19th century, politics and socioeconomic conditions became increasingly intertwined in Europe, producing a new definition of government functions, including a greatly expanded state and a new political spectrum. Linkage to cultural trends also showed through an interest in hardheaded realism. Predictably, political conditions in eastern Europe, though mirroring some of the general developments, remained distinctive.

The decades between 1850 and 1870 served as a crucial turning point in European politics and diplomacy, somewhat surprisingly given the apparent victory of conservative forces over the revolutions of 1848. Reactionary impulses did surface during these years. A Conservative Party eager to hold the line against further change emerged in Prussia. A number of governments made new arrangements with the Roman Catholic church to encourage religion against political attacks. Pope Pius IX, who had been chased from Rome during the final surge of agitation in 1848, turned adamantly against new political ideas. In the *Syllabus of Errors* accompanying the encyclical *Quanta cura* ("With What Great Care," 1864), he denounced liberalism and nationalism and insisted on the duty of Roman Catholic rulers to protect the established church, even against religious toleration. The proclamation of papal infallibility (1870) was widely seen as another move to firm up church authority against change.

Many conservative leaders, however, saw the victory over revolution as a chance to innovate within the framework of the established order. They were aided by a pragmatic current among liberals, many of whom were convinced that compromise, not revolution, was the only way to win reform. Thus in Britain Benjamin Disraeli, the Conservative leader in the House of Commons, in 1867 sponsored a new suffrage measure, which granted the vote to most urban workers; Disraeli hoped that the new voters would support his party, and some of them did so. In France Emperor Napoleon III, who had insisted on an authoritarian regime during the 1850s, began to sponsor major industrial development while maintaining an active foreign policy, designed to win growing support for the state. In the 1860s, pressed by diplomatic setbacks, Napoleon also granted liberal concessions, expanding parliamentary power and tolerating more freedom of press and speech. The Habsburg monarchy promoted an efficient, largely German bureaucracy to replace the defunct manorial regime and in the 1860s sought to make peace with the leading nationalist movement. In the *Ausgleich* ("compromise") of 1867, Hungary was granted substantial autonomy, and separate parliaments, though based on limited suffrage, were established in Austria and Hungary. This result enraged Slavic nationalists, but it signaled an important departure from previous policies bent on holding the line against any dilution of imperial power.

The key centres of dynamic conservatism, however, were Italy and Germany. In the Italian state of Piedmont during the early 1850s, the able prime minister, Camillo di Cavour, conciliated liberals by sponsoring economic development and granting new personal freedoms. Cavour worked particularly to capture the current of Italian nationalism. By a series of diplomatic maneuvers, he won an alliance with France against Austria and in an 1858–59 war drove Austria from the province of Lombardy. Nationalist risings followed elsewhere in Italy, and Cavour was able to join these to a new Italian state under the Piedmontese king. The resultant new state had a parliament, and it vigorously attacked the power of the Roman Catholic church in a liberal-nationalist combination that could win support from various political groups.

Inspired in part by Italian example, a young chief minister in Prussia, Otto von Bismarck, began a still more important campaign of limited political reform and nationalist aggrandizement. The goal was to unite Germany under Prussia and to defuse liberal and radical agitation. In a series of carefully calculated wars during the 1860s, Bismarck first defeated Denmark and won control over German-speaking provinces. He then provoked Austria, Prussia's chief rival in Germany, and to general surprise won handily, relying on Prussia's well-organized military might. A Prussian-dominated union of northern German states was formed. A final war with France, in 1870–71, again resulted in Prussian victory. This time the prize was the province of Alsace and part of Lorraine and agreement with the southern German states to form a single German empire under the Prussian ruler. This new state had a national parliament with a lower house based on universal manhood suffrage but an upper house dominated by Prussia, whose class voting system assured primary power to the upper classes. As in Italy, appointment of ministers lay with the crown, not parliament. Freedoms of press and speech were extended and religious liberty expanded to include Jews, but the government periodically intervened against dissident political groups.

Bismarck's German policy

These developments radically changed Europe's map, eliminating two traditional vacuums of power that had been dominated by a welter of smaller states. Nationalism was triumphant in central Europe. At the same time, regimes had been created that, buoyed by nationalist success, appealed to moderate liberal and conservative elements alike while fully contenting neither group. The old regime, attacked for so many decades, was gone, as parliamentary politics and a party system predominated through western and central Europe. Concurrently, impor-

tant powers for throne and aristocracy remained, as liberals either compromised their policies or went into sullen, usually ineffective, opposition.

A slightly different version of the politics of compromise emerged in France in the 1870s. Defeated by Prussia, the empire of Napoleon III collapsed. A variety of political forces, including various monarchist groups, contended for succession after a radical rising, the Paris Commune, failed in 1871. Eventually, through a piecemeal series of laws, conservative republicans triumphed, winning a parliamentary majority through elections and proclaiming the Third Republic. This was a clearly liberal regime, in which parliament dominated the executive branch amid frequent changes of ministry. Freedoms of press, speech, and association were widely upheld, and the regime attacked the powers of the church in education and other areas. At the same time, dominant liberals pledged to avoid significant social change, winning peasant and middle-class support on this basis.

The Third Republic

With the emergence of the Third Republic, the constitutional structure of western Europe was largely set for the remainder of the 19th century. All the major nations (except Spain, which continued to oscillate between periods of liberalism and conservative authoritarianism) had parliaments and a multiparty system, and most had granted universal manhood suffrage. Britain completed this process by a final electoral reform in the 1880s. Belgium, Italy, and Austria held out for a longer time, experiencing considerable popular unrest as a result, though voting reforms for men were completed before 1914. Important political crises still surfaced. Bismarck warred with the Roman Catholic church and the Catholic Centre Party during the 1870s before reaching a compromise agreement. He then tried to virtually outlaw the socialist party, which remained on the defensive until a liberalization after he fell from power in 1890. During the 1890s, France faced a major constitutional crisis in the Dreyfus affair. The imprisonment of Alfred Dreyfus, a Jewish army officer falsely accused of treason, triggered a battle between conservative, Catholic, and military forces, all bent on defending the authority of army and state, and a more radical republican group joined by socialists, who saw the future of the republic at stake. The winning pro-Dreyfus forces forced the separation of church and state by 1905, reducing Catholicism's claims on the French government and limiting the role of religion as a political issue.

The politics of compromise also affected organized religion, partly because of attacks from various states. A number of Protestant leaders took up social issues, seeking new ways to reach the urban poor and to alleviate distress. The Salvation Army, founded in Britain in 1878, expressed the social mission idea, whereby practical measures were used in the service of God. Under a new pope, Leo XIII, the Roman Catholic church moved more formally to accommodate to modern politics. The encyclical *Rerum Novarum* ("Of New Things," 1891) urged Catholics to accept political institutions such as parliaments and universal suffrage; it proclaimed sympathy for working people against the excesses of capitalism, justifying moderate trade union action though vigorously denouncing socialism. Steps such as this muted religious issues in politics, while on the whole relegating organized religion to a more modest public role.

In general, the resolution of major constitutional issues led to an alternation of moderate conservative and liberal forces in power between 1870 and 1914. Conservatives, when in charge, tended to push a more openly nationalistic foreign policy than did liberals; liberals, as the Dreyfus affair suggested in France, tended to be more concerned about limiting the role of religion in political life. Both movements, however, agreed on many basic goals, including political structure itself. Both were capable of promoting some modest social reforms, though neither wished to go too far. In Italy, conservatives and liberals were so similar that commentators noted a process of transformism (*trasformismo*), by which parliamentary deputies, regardless of their electoral platforms, were transformed into virtually identical power seekers once in Rome.

As the range of dispute between conservatives and liberals narrowed (save for fringe movements of the radical right that distrusted parliamentary politics altogether), the most striking innovation in the political spectrum was the rise of socialist parties, based primarily on working-class support though with scattered rural and middle-class backing as well. Formal socialist parties began to take shape in the 1860s. They differed from previous socialist movements in focusing primarily on winning electoral support; earlier socialist leaders had either been openly revolutionary or had favoured setting up model communities that, they thought, would produce change through example. Most of the socialist parties established in the 1860s and '70s derived their inspiration from Karl Marx. They argued that revolution was essential and that capitalists and workers were locked in a historic battle that must affect all social institutions. The goal of socialist action was to seize the state, establishing proletarian control and unseating the exploitative powers of capitalism. In practice, however, most socialist parties worked through the political process (with support for trade union activities), diluting orthodox Marxism. Universal suffrage created a climate ripe for socialist gains, particularly since, in most countries, these parties were the first to realize the nature of mass politics. They set up permanent organizations to woo support even apart from election campaigns and sponsored impassioned political rallies rather than working behind the scenes to manipulate voters. Newspapers, educational efforts, and social activities supplemented the formal political message.

Formation of socialist parties

By the 1880s the German socialist party was clearly winning working-class support away from the liberal movement despite Bismarck's antisocialist laws. By 1900 the party was a major political force, gaining about two million votes in key elections and seating a large minority of parliamentary deputies. By 1913 the German party was polling four million votes in national elections and was the largest single political force in the nation. Socialist parties in Austria, Scandinavia, and the Low Countries won similar success. Socialism in France and Italy, divided among various ideological factions, was somewhat slower to coalesce, but it too gained ground steadily. In 1899 a socialist entered the French Cabinet as part of the Dreyfusard coalition, shocking orthodox Marxists who argued against collaboration with bourgeois politicians. By 1913 the French party had more than a hundred delegates in parliament. British socialism grew later and with less attention to formal ideology. The Labour Party was formed in the 1890s with strong trade union connections; it long lagged behind the Liberals in winning workers' votes. Nevertheless, even in Britain the party was a strong third force by 1914. In many countries socialists not only formed a large national minority capable of pressing government coalitions but also won control of many municipal governments, where they increased welfare benefits and regulated urban conditions for the benefit of their constituents.

The rise of socialism put what was called "the social question" at the forefront of domestic policy in the late 19th century, replacing debates about formal constitutional structure. Fear of socialism strengthened the hand of ruling conservative or liberal coalitions. At the same time, success mellowed many socialist leaders. In Germany about 1900 a revisionist movement arose that judged that revolution was not necessary; it was thought that Marxism should be modified to allow for piecemeal political gains and cooperation with middle-class reformers. Most parties officially denounced revisionism in favour of stricter Marxism, but in fact they behaved in a revisionist fashion.

Changes in government functions. Shifts in the political spectrum and larger issues of industrial society prompted important changes in government functions through the second half of the 19th century. Mass education headed the list. Building on earlier precedents, most governments in western Europe established universal public schooling in the 1870s and '80s, requiring attendance at least at the primary levels. Education was seen as essential to provide basic skills such as literacy and numeracy. It also was a vital means of conditioning citizens to loyalty to the national government. All the educational systems vigorously pushed nationalism in their history and literature courses. They tried to standardize language, as against minority

dialects and languages (opposing Polish in Germany, for example, or Breton in France).

A second extension of government functions involved peacetime military conscription, which was resisted only in Great Britain. Prussia's success in war during the 1860s convinced other continental powers that military service was essential, and conscription, along with steadily growing armaments expenditures, enhanced the military readiness of most governments.

Governments also expanded their record-keeping functions, replacing church officials. Requirements for civil marriages (in addition to religious ceremonies where desired), census-taking, and other activities steadily expanded state impact in these areas. Regulatory efforts increased from the 1850s. Central governments inspected food-processing facilities and housing. Inspectors checked to make sure that safety provisions and rules on work hours and the employment of women and children were observed. Other functionaries carefully patroled borders, requiring passports for entry. Most countries (Britain again was an exception) increased tariff regulations in the 1890s, seeking to conciliate agriculturalists and industrialists alike; while not a new function, this signaled the state's activist role in basic economic policy. Most European governments ran all or part of the railroad system and set up telephone services as part of postal operations.

Educator, record-keeper, military recruiter, major economic actor—the state also entered the welfare field during the 1880s. Bismarck pioneered with three social insurance laws between 1883 and 1889—part of his abortive effort to beat down socialism—that set up rudimentary schemes for protection in illness, accident, and old age. Austria and Scandinavia imitated the German system, while the French and Italian governments established somewhat more voluntary programs. Britain enacted a major welfare insurance scheme under a Liberal administration in 1906, and in 1911 it became the first country to institute state-run unemployment insurance. All these measures were limited in scope, providing modest benefits at best, but they marked the beginnings of a full-fledged welfare state.

Early social welfare legislation

The growth of government, and the explosion of its range of services, was reflected in the rapid expansion of state bureaucracies. Most countries installed formal civil service procedures by the 1870s, with examinations designed to assure employment and seniority by merit rather than favouritism. State-run secondary schools, designed to train aspiring bureaucrats, increased their output of graduates. Taxation increased as well, and during the 1890s many nations installed income tax provisions to provide additional revenue. Quietly, amid many national variants, a new kind of state was constructed during the late 19th century, with far more elaborate and intimate contacts with the citizenry than ever before in European history.

Reform and reaction in eastern Europe. Political patterns in Spain, the smaller nations of southeastern Europe, and, above all, Russia followed a rather different rhythm. Parliamentary institutions were installed in some cases after 1900, but these were carefully controlled. Censorship severely limited political expression.

Russia continued a reformist mode for several years after the emancipation of the serfs. New local governments were created to replace manorial rule, and local assemblies helped regulate their activities, giving outlet for political expression to many professional people who served these governments as doctors, teachers, and jurists. Law codes were standardized and punishments lightened. The military was reformed and became an important force in providing basic education to conscripts. No national representative body existed, however, as tsarist authority was maintained. Further, after Alexander II's assassination by anarchists in 1881, the government reversed its reformist tendencies. Police powers expanded. Official campaigns lashed out brutally at Jews and other national minorities. Agitation continued at various levels, among intellectuals (many of whom were anarchists) and among workers and peasants. A small liberal current took shape within the expanding middle class as well.

Economic recession early in the 1900s was followed by a shocking loss in a war with Japan (1904–05). These conditions led to outright revolution in 1905, as worker strikes and peasant rioting spread through the country. Nicholas II responded with a number of concessions. Redemption payments were eased on peasants, and enterprising farmers gained new rights to acquire land, creating a successful though widely resented kulak class in the countryside. Rural unrest eased as a result. On the political front a national parliament, or Duma, was established. Socialist candidates, however, were not allowed to run, and the Duma soon became a mere rubber stamp, unable to take any significant initiative. Repression returned and with it substantial popular unrest, including growing illegal trade unions. Russia did not make the turn to compromise politics, and in the judgment of many historians renewed revolution loomed even aside from the outbreak of war in 1914.

Diplomatic entanglements. Many features of Europe's evolution in the late 19th century turned renewed attention to the diplomatic and military arena. Advancing industrialization heightened competition among individual nations and created a massive power disparity between Europe and most of the rest of the world. Wealth allowed new international ventures. Specific inventions such as steamships (capable of rapid oceanic transit and travel upstream in such previously unnavigable waters as the rivers of Africa), machine guns, and new medicines provided fresh opportunities for world domination. The changes in Europe's map caused by Italian and German unification inevitably prompted diplomatic reshufflings. The politics of compromise encouraged governments to rely on diplomatic goals as a means of pleasing the new and somewhat unpredictable electorate.

During the 1870s and '80s Europe itself remained relatively calm. Bismarck, by far the ablest statesman on the scene, professed the newly united Germany to be a satisfied power, interested only in maintaining the European status quo. His most obvious opponent was recently defeated France, and he carefully constructed a diplomatic network that would make French enmity impotent. Peacetime alliances were an innovation in European diplomacy, but for a time they had the desired stabilizing effect. Bismarck conciliated the Habsburg regime, forming an arrangement between the two emperors. In 1882 he joined Italy to this understanding, completing a Triple Alliance on the basis of assurances of mutual aid against outside attack. To this Bismarck added a separate understanding with Russia. These linkages required sensitive juggling, because they loosely grouped some potential opponents (such as Russia and the Habsburgs). They did offer a means of isolating France, particularly since Bismarck also cultivated good relations with Britain, which was interested primarily in colonial expansion where France was its most obvious rival.

The Triple Alliance

Even before it was fully constructed, Bismarck's plan to stabilize Europe faced an important challenge. Revolts in the Balkans, in areas nominally under Ottoman control, called attention to what was then Europe's most volatile area. Effective Ottoman dominion over this region had been declining steadily along with the vigour of the government more generally, and nationalist fervor, spreading from western Europe, had galvanized many ethnic groups. Revolts in Serbia and Romania won partial independence earlier in the 19th century, and Greece had gained national status outright. In the 1870s rioting broke out in several regions, and Serbia and another small nation, Montenegro, declared war on the Ottoman empire. Russia joined in, to protect its Slavic "brethren" and to gain new territory at Turkey's expense. Easy victories followed, and a large new Bulgarian state was proclaimed, along with Russian acquisitions along the Black Sea. At this point Austria-Hungary and Britain, both interested in stability in the region, intervened. Bismarck, anxious for peace, called a Berlin Congress to win an acceptable compromise. The result was a smaller Bulgaria, full independence for Serbia, Montenegro, and Romania, and Austrian administration of the Slavic provinces of Bosnia and Herzegovina. Britain gained the island of Cyprus, which gave it a closer watchdog position over its routes to India, and France was encouraged to take over Tunisia. Each country save

Italy got something, Germany gaining satisfaction as a new great power and honest broker. Bismarck's alliance system, designed to conciliate Russia and the Habsburgs and to harness Italian ambitions, unfolded in the wake of the Congress of Berlin.

The scramble for colonies. The most obvious result of the Congress and of nationalist yearnings, juxtaposed with a more structured European map, was a new and general scramble for colonies in other parts of the world. Even before the 1870s some new gains had occurred. French explorers fanned out in equatorial Africa, and a French mission began the conquest of Indochina in the 1860s. Many European nations exhibited a growing interest in colonies as sources of raw materials and new markets and as potential outlets for excess population and for administrators who could not be accommodated at home. Opportunities for individual adventurism and profit also ran high. Overriding motivations for the climactic imperialist scramble involved a desire to appeal to domestic nationalism and an interest in maintaining or gaining place as world powers. New nations such as Italy and Germany sought empires to prove their status; France sought expansion to compensate for its humiliating defeat at Germany's hands; Britain pressed outward in order to protect existing colonies. Russia, and at the century's end the United States and Japan, also joined the competition.

Between 1880 and 1900 much of Asia was divided. Britain held Burma; Britain, Germany, France, and the United States divided the Pacific islands of Polynesia. All the major European powers save Italy took advantage of China's weakness to acquire long-term leases on port cities and surrounding regions, easily putting down the Chinese Boxer Rebellion against Western encroachments in 1899–1900. Germany gained new advisory and investment roles within the Ottoman Empire, while Britain and Russia divided spheres of influence in Afghanistan; Britain also effectively controlled several small states on the Persian Gulf.

The dismemberment of Africa was even more complete. Portugal expanded its control over Angola and Mozambique, Belgium took over the giant Congo region, and Germany gained new colonies in southern Africa. Britain and France, the big winners, gained new territory in West Africa, and Britain built a network of colonies in East Africa running from South Africa to Egypt. The French occupation of Morocco and the Italian conquest of Tripoli, after 1900, completed the process. Only Ethiopia remained fully free, defeating an Italian force in 1896.

Prewar diplomacy. By the early years of the 20th century the major imperialist gains had been completed, but some of the excitement that the process had generated remained, to spill back into European diplomacy. Germany had begun construction of a large navy, for example, in the 1890s, in part to assure its place as an imperialist power; but this development, along with Germany's rapid industrial surge, threatened Britain. France ran a massive empire, but its nationalistic yearnings were not fully satisfied and the humiliating loss of Alsace-Lorraine had not been avenged. Russia encountered a new opponent in the Far East in the rise of Japan. The Japanese, fearful of Russian expansion in northern China, defeated the tsarist forces in the Russo-Japanese War in 1904–05, winning Korea in the process. The unstable Russian regime looked for compensatory gains in the hothouse of the Balkans rather than in the distant reaches of Asia. The stage was set for intensification of European conflicts.

Furthermore, the complex alliance system developed by Bismarck came unraveled in the 1890s, following the statesman's removal from power at the hands of a new emperor, William II. Germany did not renew its alliance with Russia, and during the 1890s an alliance developed between Russia and France, both fearful of Germany's might. Britain, also wary of German power, swallowed its traditional enmity and colonial rivalries with France, forming a loose Entente Cordiale in 1904; Russia joined this understanding in 1907. Europe stood divided between two alliance systems.

The Balkan Wars

In 1908 Austria-Hungary annexed Bosnia and Herzegovina. It was eager to strike a blow against South Slavic nationalism, which threatened the multinational Habsburg empire. This move antagonized Russia and Serbia, the latter claiming these territories as part of its own national domain. In 1912 Russia aided several of the Balkan states in a new attack on the Ottoman Empire, with the allies hoping to obtain Macedonia. The Balkan nations won, but they quarreled with each other in the Second Balkan War in 1913. Further bitterness resulted in the Balkan region, with Serbia, though a winner in both wars, eager to take on Austria-Hungary directly.

On June 28, 1914, Gavrilo Princip, a Serbian nationalist, assassinated the Austrian Archduke Francis Ferdinand. Austria-Hungary resolved to crush the Serbian threat in response. Germany supported its Austrian ally, partly because it feared that its most reliable partner needed a victory and partly because many leaders judged that war had become inevitable and was preferable sooner than later,

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Building cannons in the Krupp gun factory, Essen, Ger., 1904.

given ongoing military modernizations in France and Russia. Russia refused to abandon Serbia, and France hewed to its alliance with Russia. Last-minute negotiations, led by Britain, failed. Russia began a general mobilization following Austria's July 28 attack on Serbia. Germany, eager to take advantage of Russia's slowness by striking a lightning blow in the west, then invaded neutral Belgium and pushed into northern France. Britain, briefly hesitant, was committed by treaty to defend Belgium and entered the fray on August 4, and World War I was under way.

The patterns of European diplomacy in the late 19th century are not an unrelieved story of nationalist rivalries. From the 1850s onward European nations signed a number of constructive international agreements designed to link postal systems, regularize principles of international commercial law, and even install some humanitarian agreements in the event of war. The International Red Cross was one fruit of these activities, as was the establishment of a World Court, in The Netherlands, to help settle international disputes. But efforts to negotiate a reduction of armaments, in a series of conferences beginning in 1899, failed completely amid growing national military buildups. Britain and Germany, in particular, refused to abandon their naval race, which took a new turn with the development of the massive Dreadnought battleship soon after 1900.

World War I, a bloody struggle that served to reduce Europe's world role, resulted not only from escalating international tensions but also from domestic strains. Russia and Austria-Hungary, internally pressed by social and nationalist strife, looked to diplomatic successes, even at the cost of war, as a means of diverting internal discontents, and the alliance system trapped more stable nations into following suit. Germany, Britain, and France, beleaguered by growing socialist gains that frightened a conservative leadership and urged on by intense popular nationalism, also accepted war not only as a diplomatic tool but also as a means of countering internal disarray. Cultural emphasis on irrationality, spontaneity, and despair contributed to the context as well. War thus resulted from a number of basic developments in 19th-century Europe, just as its catastrophic impact resulted from the military technologies that the 19th-century industrial revolution had created. (P.N.S.)

MODERN CULTURE

In the last quarter of the 19th century European thought and art became a prey to self-doubt and the fear, as well as the pleasures, of decadence. Writers as different as Baudelaire and Matthew Arnold, Henry Adams and Flaubert, Ruskin and Nietzsche had begun from the mid-century onward to express their revulsion from the banality and smugness of surrounding humanity, debased—they felt—by "progress." It seemed as if with the onset of positivism and science, *Realpolitik* and Darwinism, realistic art and popular culture, all noble thought and true emotion had been suffocated. The only things that stood out from banality and smugness were their own appalling extremes—vulgarity and arrogance—against which all the weapons of the mind seemed powerless.

The diminished influence of the intellectuals

Such intellectuals and artists were hopelessly outnumbered not only in the literal sense but also in the means of influencing culture. A newspaper that reached half a million readers with its clichés, its serial story, and its garish illustrations "educated" the people in a fashion that actively prevented any understanding of high culture. The barrier was far more insurmountable than mere ignorance or illiteracy, and it was cutting off not just the populace but also—to use Arnold's terms—the barbarian upper class and the Philistine middle class. Similarly, Nietzsche anatomized what he called the culture-Philistine; that is, the person whose mind fed on middling ideas and "genteel" tastes halfway between those of the populace and those of the genuinely cultivated. Numerous artists and writers, high in repute and believed then to be the leaders of modern civilization, provided the materials for these conscientious consumers of art, literature, and "sound opinion" in every field. In other words, the prudent, self-limiting impulse of Realism after 1848 had generated the middlebrow, while the evolution of industrial democracy had generated the mass man. By the late 1880s the gap between this compact army with its honoured officers and common soldiers and the hostile, half-visible avant-garde was a permanent feature of cultural evolution.

Out of the uneven conflict came increasingly violent expressions of hatred and disgust, and the age that had defined Realism as the commonplace and average gradually succumbed to a variety of proffered opposites. Their forms and tendencies can be grouped into half a dozen kinds, not all on the same intellectual or artistic plane, nor all distinctly named then or now. One discerns first a retreat from the ugly world into a species of Neoclassicism. Such were the French poets known as Parnassians. Strict form, antique subjects, and the pose of impassivity constitute their hallmark. In painting, the work of Puvis de Chavannes stands in parallel.

In music, the explicit revolt against Wagner and Liszt, of which Brahms was made the torchbearer, offers similarities, particularly in the desire to learn and employ the "purer" forms of an earlier time. Likewise, the shift in tone and temper of the later poems of Tennyson, Arnold, or Gautier; the resurgence of Thomist orthodoxy in Roman Catholic thought; the haughty detachment in the plays of Becque and those of Ibsen's middle period, all suggest a search for stability, for a fixed point from which to judge and condemn contemporary "progress."

Symbolism and Impressionism. Next, it appeared that those who wanted to withdraw from vulgar actuality were making of art with a capital *A* an independent region of thought and feeling into which to escape, by which to reduce the pain of living. Steady contemplation of "the beautiful" created a "truer" world than the one accepted by ordinary people as real. Walter Pater, a critic writing from the shelter of Oxford, gave eloquent expression to this conception of life, in which every possible minute must be charged with fine and rare sensation. His brilliant disciple Oscar Wilde made the doctrine so clear and persuasive that it generated a characteristic atmosphere, now known as Aestheticism, or more simply as "the Nineties."

This creed of self-redemption through art is related to the movements known as Symbolism and Impressionism. It is noteworthy that the Impressionist painters were able to take as subjects some of the sights that most depressed their fellow man and by recomposing them in brilliant, shimmering colour to create a refreshing world of new sensation. Subject once again mercifully disappeared. As Monet said: "The principal subject in a painting is light."

The Symbolists in literature had a more difficult task than the painters, because their medium, words, must be shared with all those who speak the language for ordinary purposes. To disinfect grammar and vocabulary for poetry and "art prose" required severe measures. All set phrases had to be broken up, unusual words revived or common ones used in archaic or etymological senses; syntax had to be bent to permit fresh juxtapositions from which new meanings might emerge; above all, the familiar rhetoric and rhythms had to be avoided, until the literary work, poetry or prose, created the desired "new world." It is a world difficult to access but worth exploring, all its tangible parts being the symbols of a radiant reality beyond—in short, the antithesis of a newspaper editorial.

In music there was no need of any indirect device to establish the mood of Impressionism. It was already to be found here and there in the great Romantics, and when the new generation began to compose on themes drawn from contemporary literature, the hints and opportunities needed only a delicate genius to develop them into a style. Debussy was that genius, soon followed by Ravel, Delius, Hugo Wolf, and others. Alike, yet independently of one another, they replaced eloquence, melodic clarity, and harmonic consecutiveness by capricious melodic contour and pointillist chord progressions to produce the shimmer and mystery of musical Impressionism.

Aestheticism. To those who dedicated their lives to Symbolist literature and criticism the name of aesthetes is often given, for it was at this time, from 1870 to the end of the century, that questions of aesthetics became the intense concern of artists, critics, and a portion of the public.

The phrase "art for art's sake," which the Romanticists had toyed with, was revived and made the hallmark of high art. Whatever claimed the attention of the intellectual elite must receive this authentication, which guaranteed that no ulterior motive, such as propaganda, and no appeal to the middlebrow audience was discernible in the poem, painting, or musical composition. Common subject matter, ease of understanding, accessibility were signs of compromise with vulgar taste. Having cut loose from evil society, art repudiated its former role of moral teacher and even of communicator; it was—or was to be—completely "autonomous," else it could not serve its devotees as a refuge from intolerable workaday existence.

Yet Aestheticism was by no means as languid and fatalistic as it tried to appear. Writers such as Oscar Wilde, George Moore, Stéphane Mallarmé, and Edmond and Jules Goncourt, though promoting the idea of art as spiritual shelter, took an active part in current affairs. Moore wrote naturalistic novels; Mallarmé gave interviews to the press and wrote advertisements for perfume and other luxuries; and Wilde, whom it is easy, because of his notoriety on many counts, to dismiss as colourful but ephemeral, was an effective propagandist in the assault on the Victorian ethos. He was not a symptom but the representative man. His book reviewing and critical essays, his story *The Picture of Dorian Gray,* his great *Ballad of Reading Gaol,* the autobiographical *De Profundis,* and the greatest farce in the language, *The Importance of Being Earnest,* together form a kind of sourcebook for the period and have also lasted as literature. What Wilde accomplished through these works was the liberation of English literature from ancestral (and not merely Victorian) preconceptions. He reconnected England with the Continent artistically by phrasing with finality their different assumptions. He showed that art could be morally responsible only by discarding moralism. In a word, he played again in 1890 the role Gautier had played in France in 1835 with his anti-bourgeois diatribe in *Mademoiselle de Maupin.* Whoever, starting with Wilde or Gautier, wishes to follow the historical sequence and recapture the atmosphere in which this activity went on will find no better source than the *Journal* of the Goncourts, who were the inventors of a mannered "art prose," of contemporary lives, characters, and gossip.

The reader of their voluminous pages will also find there references to the movement called Naturalism, which does not merely parallel but also intermingles with Symbolism and Impressionism. The Goncourts themselves wrote a number of Naturalistic novels; their friend Zola was the theorist and greatest master of the genre; another novelist, Joris-Karl Huysmans, passed from Naturalism to Symbolism, as did several other writers. In the poets Rimbaud and Verlaine, as later in the Irish Yeats, the elements of the two tendencies alternated or mixed.

Naturalism. The name Naturalism suggests the philosophy of science, and the connection is genuine. Zola thought that in his great series of novels, *Les Rougon-Macquart,* he was studying the "natural and social history" of a family during the time of Napoleon III. The claim was bolstered by the method Zola used of gathering data like a scientist—every material fact could be proved by reference to actuality or statistics. Naturalism would thus appear to be an intensification of Realism, as indeed it was—more "research." It differed markedly in spirit, however. Realism professed to be depiction of the commonplace in a mood of stoicism or indifference—a photographic plate from a camera held almost at random in front of unselected mediocrity; it was, as Flaubert was the first to say, a refusal to share previous Romanticist hopes and interests. Naturalism, on the contrary, readmitted purpose and selectivity. Each novel was a "study" designed to exhibit and denounce the dismal truths of social existence, for which purpose the worst are the best. Zola's novels throb with a passionate love of life, a life which he showed as tortured and twisted by character and condition. In the end he defined his scientific or "experimental" novel as "a corner of nature seen through a temperament." The aim of the Naturalists was not only to show but to show up; they meant to teach the great prosperous middle class how those beneath them lived and even beyond that to disgust the sensitive with the human condition, whatever its social embodiment. In this effort it shares with the aesthetes the animus of denunciation.

In the plastic arts, a plausible counterpart of Naturalism is the work of those known as Postimpressionists, notably Cézanne and van Gogh in painting, Rodin and Maillol in sculpture. Their various styles and aims had a common result in restoring solidity and "weight" to the visual object after the fluidity and lightness of Impressionism.

Musical naturalism was, by contrast, an attempt at dramatic literalness. Richard Strauss boasted that he could render a soup spoon. Actually, he could not and did not. The noises of his *Sinfonia Domestica* are standard orchestral sounds fitted with a preliminary explanation, like the libretto or synopsis of a Wagnerian or other opera. When the sheep bleat in Strauss's *Don Quixote,* the clarinets play notes that are decorative on their own account and do not in the least suggest wool. It is rather the thickness of Strauss's orchestration and chromatic harmony that connect him with naturalist doctrine—the headlong embrace with matter. And so it is also in the operas of Bruneau or Charpentier or in the *verismo* of Puccini and the late Italian school generally. Music remains atmospheric; never, except in Wagner's system, denotative.

This definition of Naturalism, coupled with the aesthetic, or "art for art's sake," impetus in Symbolism and with the Impressionists' transmutation of concreteness into light, justifies the name of Neoromanticism that has been given to the cultural temper with which the 19th century ended. After the glum self-repression of the middle period, it was an outburst of vehement self-assertion, whether directed inward or outward. "Art for art's sake" and Naturalism are indeed but twin branches of one doctrine: art for life's sake.

The new century. In 1895 George Bernard Shaw said: "France is certainly decadent if she thinks she is." The remark is characteristic of Shaw, but it is also indicative of a new wave of energy. From under the despair and decadence, the scattered retreats and the violent nihilism, the same human strength that produced Symbolist and Naturalist art was trying to reshape the civilization that all found so unsatisfactory.

In England, the Fabians, of whom Shaw was one, were preaching the "inevitableness of gradualism" toward the socialist state. It was they, seconded by the growing strength of the trade unions after a spectacular dock strike of 1889, who paved the way to Labour governments and the British welfare state. Throughout Europe, socialism was no longer the creed of a lunatic fringe but was the ideal of many among the masses and the intellectuals. The original fight for liberty and democracy in political action had turned into a fight for economic democracy—freedom from want. Laissez-faire liberalism had turned inside out, and the liberal imagination at work in the many brands of socialism now demanded state interference to remove the appalling conditions causing all the despair.

The growth of socialism

Arts and Crafts movement. Among the socialists belonging to no party, Ruskin and William Morris worked also to effect immediate changes in the quality of their surroundings: they started the so-called Arts and Crafts movement, whose aim was to make objects once again beautiful. Because machine industry produced only the "cheap and nasty" (as it was commonly called), they tried to produce by hand the cheap and handsome—good furniture, hangings, and household articles; fast dyes of good colour; well-printed books on good paper; and jewelry and ornaments of all kinds that showed visual talent as well as manual skill. In a word, the movement reinstated the ideal of design and succeeded in forcing it on machine industry itself. Within two decades manufacturers began to hire artists as designers, and by 1910 the 20th-century omnipresence of design, from clothes to print and from gadgetry to packaging, was a fait accompli. The visual revolution can be seen easily by looking back with modern eyes to a page of advertising at the turn of the century.

New trends in technology and science. In parallel with the new craftsmanship, the new technology of the 1900s began to give hope of wider improvements. The use and transmission of electric power suggested the possibility of

the clean factory, all glass and white tile. Better machines, new materials and alloys, a greatly expanded chemical industry—all supplied more exact, more functional, less hazardous objects of use and consumption, while the application of science to medicine nourished the hope of greatly reducing the physical ills of mankind. Those closest to all these developments were certainly not among the despairers and fugitives from the world. Like all those who struggle successfully with practical difficulties, they were inspirited by what they knew to be demonstrable progress along their chosen lines.

The same outlook animated workers in the natural and social sciences. It was for both a time of transformation, and genuine novelty exerted its usual invigorating effect. From the 1880s onward it had been clear that simple mechanistic explanations based on "dead" matter were inadequate. The Michelson-Morley experiment of 1887 had given the coup de grace to the mere push-pull principle by showing that, though light consisted of waves, the waves were not in or of anything, such as the ether, which did not exist. Even earlier, James Clerk Maxwell's attempt to work out the facts of electromagnetism on Newtonian principles had failed. And on the philosophic front, the notion of natural "laws" was being radically modified by thinkers such as Poincaré, Boutroux, Ernst Mach, Bergson, and William James. All this prepared the ground for the twin revolutions of relativity and quantum theory on which the 20th-century scientific regime is based.

Rediscovery of genetics

The decline of the machine analogy had its counterpart in the biological sciences. With narrow Darwinian dogmas in abeyance, the genetics of Gregor Mendel were rediscovered, and a new science was born. The fixity of species was again regarded as important (Bateson), while the phenomenon of large mutations (de Vries) caught the public imagination, just as the slow, small changes had done 60 years earlier. The elusive "fitness of the environment" was being considered of as much importance in the march of evolution as the fitness of the creature. Vitalism once more reasserted its claims, as it seems bound to do in an eternal seesaw with mechanism.

The social sciences. Finally, in the social sciences, fresh starts were made on new premises. Anthropology dropped its concern with physique and race and turned to "culture" as the proper unit of scientific study. Similarly in sociology, Durkheim, seconded by Tönnies, Weber, Tarde, and Le Bon, concentrated on "the social fact" as an independent and measurable reality equivalent to a physical datum. Psychology, also long under the exclusive sway of physics and physiology, now established at the hands of William James that the irreducible element of its subject matter was the "stream of consciousness"—not a compound of atomized "ideas" or "impressions" or "mind-stuff" but a live force in which image and feeling, subconscious drive and purposive interest, were not separable except abstractly. A last domain of research was mythology, to the significance of which James George Frazer's *The Golden Bough* gave massive witness, thereby exerting proportional influence on literature and criticism.

Reexamination of the universe. The net effect of these innovations in the sciences of man and of nature was liberating. Whatever each specialty or subspecialty meant to its practitioners, the persons who carry in their minds the general culture of an age took the new message to mean that the universe, formerly closed and complete like a machine, had been reopened and shown to be more alive than dead—and by the same token more mysterious, full of questions to be resolved by new research and new sciences. The term astrophysics, replacing astronomy, symbolized the change of perspective from Newton's cosmology to Einstein's. In turn, these conclusions furnished a new opportunity for the exercise of individual thought and will in the realm of mind and spirit, of ethics and religion. Man was no longer deemed an automaton, he had free choice in the all-important matters that lay outside physical science.

In philosophy, politics, and criticism this reexamination may be called the pragmatic revolution; in social and moral life, the liquidation of Victorianism. But the Pragmatic Revolution must not be thought of as being only the work of those who, like James, called themselves pragmatists. Nietzsche, Samuel Butler, Shaw, Bergson, and others constitute the headwaters of the stream of thought that issues in present-day existentialism. The common features are the turning away from absolutes and unities to pluralisms and the method of testing by consequences. Subjective and objective tests looking to future thought and action—not authority or antecedents—are to decide what is true, good, and beautiful.

Turning away from absolutes

Such an outlook, of which the refinements are, like the defects, beyond the scope of this article, is the logical and appropriate one for an age of reconstruction. It boils down to trying all things new and holding fast to that which is good; but it presupposes the creation of new things to try, and here it is allied to the liquidation of Victorianism. In morals the work of destruction generally begins by affirming the opposite of the accepted rule. An excellent source book for this attitude is Samuel Butler's *The Way of All Flesh,* written in 1885 but not published until 1903. The Victorian Tennyson had said: "'Tis better to have loved and lost than never to have loved at all." Butler said: "'Tis better to have loved and lost than never to have lost at all." This inversion of values—don't weep over loss; there are plenty of loves to be had and the more the merrier—is but an indication of method. At first the denial was uttered as humour and paradox: Butler's *Note-books,* Shaw's *Arms and the Man* (the soldier wants chocolate, not ammunition), Wilde's *The Importance of Being Earnest,* Jarry's *Ubu roi,* Strindberg's tragicomedies—to cite but a few subverters of the Victorian—all used derision and topsy-turviness to make their point.

Underneath the joke was the new purpose, which soon found open expression in positive utterance and action. In the plays of Hauptmann and Brieux, the novels and anticipations of H.G. Wells, the essays of Tolstoy, Péguy, Georges Sorel, Ellen Key, Havelock Ellis, Unamuno, Ortega y Gasset, or Shaw, the new modes of feeling and the new scale of virtues and vices are set forth with as much earnestness and vigour as the old Victorian kind.

Nor did action wait until all the books were out. From the onset of the overturn, say 1885 onward, the rebellion was a biographical fact. Individuals braved public opinion and got divorced, lived together unmarried, practiced and preached contraception, studied the psychology of sex, and defended homosexuality. Or again, the sons of the rich turned socialist, became labour leaders, and fomented syndicalist (*i.e.,* direct-action) strikes, while the daughters demanded the vote as suffragettes, assaulted policemen, and went to jail for chaining themselves to the door handles of government offices. Meanwhile, students rioted about international incidents or university affairs; schools were subjected to the devastation of the softer pedagogies; "rational clothing" exhibited itself in spite of derision, like the bicycle and the newfangled automobile; and new cults multiplied like mushrooms—outdoor sports, nudism, Theosophy, Esoteric Buddhism, Rosicrucianism, New Thought, the Society for Psychical Research, Christian Science, the Salvation Army, and the "Maximinism" of Stefan George.

Theosophy

Of these, hardly any need explanation here. But a word must be added about Theosophy if only because of its historical importance in developing Yeats's genius and for expressing once again the attraction that the "wisdom of the East" has for Westerners. Not that the doctrine elaborated by Madame Blavatsky rested on any exact knowledge of Hindu religion and philosophy. That is not its point. The point is rather that Theosophy supplied the need for quietude, mystery, transcendence, and immortality in the wearied souls of Europeans. In Theosophy the doctrine of reincarnation offers satisfaction of immortal longings and inspires to wisdom, the demands of which are periodically revealed by mahatmas, or holy men.

As for the poet Stefan George's worship of his young friend Maximin, who died at 15, it answers a similar impulse to permanent truth but with the additional urge to abolish (rather than escape) "contemporary materialism." George was but one among many European writers who wanted to found a new society in place of the actual one. What has fitly been called the politics of cultural despair

fastened on a great many saviours as the new hope—monarchy, "integral nationalism," a new aristocracy (usually tinged with intellect), technocracy (rule by science and the engineers), the proletariat (in syndicalist "cells" or communist collectives), trade and professional guilds federated in a corporate state, or again the mystic unity of "blood" and "race." In all these creeds, at least at their beginnings, the thirst for the ideal is evident; together they formed a new utopianism, of which the later fruits are familiar but quite other than those predicted: Soviet and Chinese communism, Italian fascism, German National Socialism. As the 20th century ends, the echoes and offshoots of this earlier wave of cultist thought are found in many places. Attitudes and practices derived from the East (Zen, Yoga, meditation) are taken for granted as permanent elements of Western pluralist culture, part of the broad offering of "life-styles."

In one country, as the 19th century passed into the 20th, all the violent rival energies seeking an ideal found an unexpected outlet. The occasion for battle was the conviction of a French officer for espionage; *i.e.,* the Dreyfus affair. Its cultural suggestiveness is apparent: on one side, the ideal of justice and the regard for the individual as an end in himself; on the other, the social or collective ideal typified by the army and the nation; throughout, the ideal of truth—the facts—pursued, lost, and found again in an embittered struggle that threw up a host of endemic prejudices—about race, about class, for and against intellect—to say nothing of individual egotisms and obsessions that had been charged with the force of pent-up aggression.

The prewar period. The same universal aggressiveness was to have its field day in the coming war of nations, but in the intervening decade (1905–14) occurred the remarkable outburst of a creativeness, which, for the first time since 1789, had its source elsewhere than in Romanticism.

The Cubist decade

The "Cubist decade" (as it has been conveniently called) gave the models and the methods of a new art, just as the natural and social sciences had begun to do for themselves a little earlier. Cubism in painting defined itself as a new classicism, but it was obviously not Neoclassical. In painting and sculpture, in music and poetry, and in architecture especially, the new qualities were simplicity, abstraction, and the importance of mass.

This truly modern art evidently meant to reconnect itself to contemporary life. To define it in one word, it was Constructivist. As such, it valued the products of technology, which embodied the artist's rediscovered love of matter and from which he drew suggestions of form. In the style of interior furnishing known as Art Deco, geometric angularity, smooth surfaces, plain glass, and strong colours not only matched the unadorned outside of buildings in the new International Style but also resembled the creations of the industrial engineers. Indeed, it was not unusual to see on the mantelpiece of an Art Deco living room a set of gears or some other portion of a modern machine. The latest sculptures on western streets are but a further fragmentation of the new taste for solidity, clarity, volume, and mass.

To this many-sided, original, and buoyant productiveness the war of 1914 put an instantaneous stop. It was a war of a sort Europe had not known since 1815—the nation in arms. And at that earlier time, the absence of large industry had precluded the involvement, physical and mental, of every adult citizen simultaneously throughout Europe. In 1914 Beethoven and Goethe, Wordsworth and Delacroix would have been in the trenches.

The cessation of cultural activities; their replacement everywhere by a propaganda of hate; the rapid decimation of talent and genius in the murderous warfare of bombardment and infantry assault; the gradual demoralization through four years of less and less intelligible war aims; and after the Armistice, the long sequel of horrors—starvation, dispersion, disease, and massacre—together shattered the high civilization born of the Renaissance and based on the idea of the national state. Too many able men and women had been killed for the continuity of culture. Too many intimate faiths and civil traditions had been ground down for any recovery of self-confidence and public hope to be possible. (J.Ba.)

European society and culture since 1914

"If it works, it's obsolete." First reported in or about 1950, the saying neatly expressed that period's sense of the headlong speed at which technology was changing. But equally rapid change is the hallmark of many aspects of life since 1914, and nowhere has it been more apparent than in Europe. Photographs from 1914 preserve a period appearance ever more archaic: statesmen in frock coats and top hats; early automobiles that fit their contemporary description as "horseless carriages"; biplane "flying machines" with open cockpits; long, voluminous bathing costumes. The young 20th century, its advent celebrated in such enterprises as The New Century Library—pocket editions of classics recently out of copyright—appears in such images more and more like a mere continuation of the century before.

The 19th century had itself seen the culmination of the Industrial Revolution that had begun in the 18th, but the transformation wrought by steam power, steel, machine-made textiles, and rail communications was only the beginning. Still more rapid and spectacular changes came with further advances in science and technology: electricity, telegraphy and telephony, radio and television, subatomic physics, oil and petrochemicals, plastics, jet engines, computers, telematics, and bioengineering.

The development of technology, in particular, would not have been possible without a more skilled and better educated work force. In most European countries during this period, education was extended both to more of the population and to a later age, and the numbers entering higher education greatly increased. Women began to gain access to more of the opportunities hitherto monopolized by men.

If this was a process of social leveling upward, the same process began to affect the social classes themselves. While European society remained more hierarchical than that in the United States, there began to be both greater social mobility and fewer blatant class differences as expressed in clothes, behaviour, and speech. A "mass society" began to share mass pleasures. Apparent homogeneity, both vertically within societies and horizontally between them, was accelerated by the cinema, radio, and television, each offering attractive role models to be imitated or, by older generations, deplored. Some referred to this process as "the Americanization of Europe."

Alongside these changes, and in some instances spurring them, the period since 1914 in Europe has been marked by major economic and political upheavals. The most cataclysmic were the two world wars. The second of these resulted from the rise of dictatorship in Italy and Germany; but the period also saw dictatorships in Spain and Portugal, as well as in the U.S.S.R., where the 1917 revolution was followed by the totalitarian rule of Joseph Stalin.

The two wars, of 1914–18 and 1939–45, brought the old Europe of the balance of power to the brink of destruction. Europeans were thenceforth spectators at or minor actors in the global balance of terror between the United States and the U.S.S.R. This convinced a number of European statesmen that their peace, prosperity, and position in the world could be safeguarded only if Europeans united. For much of the period after 1945, Europe remained divided between East and West, and it was only in the West that unity began to be practicable. At length, however, political changes in central and eastern Europe gradually revived old hopes of "Paneuropa."

This section describes—on a European rather than a national basis—the social, economic, intellectual, and cultural implications of these and other developments in Europe. For a complete discussion of the diplomatic events and military course of World Wars I and II, see WORLD WARS, THE. Further treatment of the diplomatic history of 20th-century Europe may be found in INTERNATIONAL RELATIONS, TWENTIETH-CENTURY.

THE GREAT WAR AND ITS AFTERMATH

The shock of World War I. The year 1914 witnessed not only the outbreak of World War I but also such very different events as the publication of James Joyce's short

stories *Dubliners,* André Gide's novel *Les Caves du Vatican,* and D.H. Lawrence's story *The Prussian Officer.* It was also the year of Pablo Picasso's painting "The Small Table," Igor Stravinsky's *Rossignol,* Sergey Diaghilev's ballet version of Nikolay Rimsky-Korsakov's *Le Coq d'or,* and the founding of the Vorticist movement in Britain by the painter and writer Percy Wyndham Lewis.

Cultural repudiation of the past

All these, in their various ways, were characteristically "modern" phenomena. The new century had already produced some fairly self-conscious attempts to criticize or repudiate the past. In 1901 the novelist Thomas Mann had chronicled in *Buddenbrooks* the decline of a Lübeck business family as it became more "refined," while in Sweden the playwright August Strindberg had savagely dissected in *The Dance of Death* a love-hate relationship on the eve of a silver wedding anniversary.

In 1903 Samuel Butler's bitter semi-autobiographical *The Way of All Flesh* had been posthumously published. In 1904 Frank Wedekind had fiercely attacked social and sexual hypocrisy in his play *Pandora's Box.* In 1905, Thomas Mann's brother Heinrich had shown a tyrannical schoolmaster ruined by an affair with a nightclub singer in *Professor Unrat* (better known in its 1928 film version as *The Blue Angel*). In 1907 the respectable writer and critic Edmund Gosse had anonymously published *Father and Son,* an autobiography recording what he called "a struggle between two temperaments, two consciences and almost two epochs."

In that same year (1907), Picasso and Georges Braque had founded the Cubist movement, with its slogan, "Paint not what you see but what you know is there." In 1909 *La Nouvelle Revue française* had been inaugurated as a forum for younger writers. In 1910 Wassily Kandinsky had produced a Postimpressionist painting defiantly entitled *First Abstract Work;* the Russian authorities had banned Rimsky-Korsakov's two-year-old *Le Coq d'or* because of its satire on government; and Sir Norman Angell had published *The Great Illusion*—an attempt to demonstrate the futility of war, even for the supposed victors. The year 1913, finally, had seen the publication of Guillaume Apollinaire's poems *Alcoöls* and the beginning of Marcel Proust's great novel *Remembrance of Things Past.*

The 20th century had begun, then, with what might be termed cultural parricide—an attack on the paternalistic, stuffily religious, and sexually repressive features of the century before. Younger writers and artists such as Joyce, Lawrence, Gide, Picasso, Stravinsky, Diaghilev, Wyndham Lewis, Ezra Pound, and T.S. Eliot formed what the novelist Ford Madox Ford called "a proud and haughty generation," determined, in Pound's words, to "make it new." Yet, looking back in 1937, Wyndham Lewis wrote ruefully:

> We are not only "the last men of an epoch" (as Mr Edmund Wilson and others have said): we are more than that, or we are that in a different way to what is most often asserted. *We are the first men of a Future that has not materialised.*

Postwar disillusion

What had blocked that future was war—"The Great War," as its stunned contemporaries called it. Not for nothing did the poet and novelist Robert Graves call his 1929 war reminiscences *Good-bye to All That.* He was bidding farewell to his prewar schooldays and to his first marriage; but what stuck in the minds of his readers was the cause of the leave-taking—the horror of life and death in the trenches of the Western Front. Graves was by no means the only writer to experience and report that visceral shock. In 1914, despite Angell's warnings, the idea of war had still borne vestiges of glamour. Idealistic young poets such as Rupert Brooke and Julian Grenfell had gone to war, initially, with eager innocence. After the slaughter on the Somme and the stalemate of trench warfare, the key word became *Disenchantment,* the apt title of C.E. Montague's account of the process. It pervaded the work of Edmund Blunden, Siegfried Sassoon, and Wilfred Owen in Britain, of Henri Barbusse (author of *Under Fire*) in France, and of Erich Maria Remarque (author of *All Quiet on the Western Front*) in Germany.

Through conscription, and, to a lesser extent, through air raids, the war had involved and affected far more of the population than any previous international conflict. By the time of the Armistice, in November 1918, there was widespread weariness in Europe and a sense of disillusion that gave the years before the war a retrospective autumn radiance, as if a dream had died.

Real deaths, indeed, had been numbered in millions. In the whole of the previous century, from the Napoleonic Wars to the Balkan Wars of 1912–1913, Europe had lost fewer than 4.5 million men. Now, at least 8 million had died in four years, while more than twice as many had been wounded, some of them crippled for life. Millions more had succumbed to the worldwide influenza epidemic that had ended in 1918. The outcome, in all countries, was imbalance between the sexes—a shortage of men that at the time was sometimes called "the problem of surplus women." During the war, women had had to be recruited into the civilian work force—in factories "for the duration," in offices sometimes for good. The net result was to encourage women's emancipation. In 1918, British women over the age of 30 were given the vote—although women's suffrage was delayed until 1944 in France and 1945 in Italy. The year 1921, moreover, saw the opening of the first birth control clinic in Britain.

Wartime comradeship helped to reduce not only barriers between the sexes but also rigidities of class. Government control of the war economy—known in Germany as *Kriegssozialismus,* or war socialism—was also a general phenomenon that left a permanent mark, in particular encouraging economic nationalism. Nowhere was this process more intense than in Russia after the Bolshevik Revolution of November 1917, where it was known as "war communism."

Nationalism had been a feature of Europe since at least the French Revolution. Napoleon had embodied its classic, democratic, or Gallic variety—the nation as a people bearing arms. Equally powerful, and more deeply rooted in history, was Romantic, cultural, or Germanic nationalism—the nation as an entity based on age-old racial and linguistic allegiance. Both forms of nationalism were encouraged by the war and its aftermath; and the latter was especially furthered by some of the provisions in the Treaty of Versailles.

The mood of Versailles. The peace conference that met in Paris from January 1919 to January 1920 and which produced, among other things, the Treaty of Versailles was both vengeful and idealistic.

Public opinion in France and Britain wished to impose harsh terms, especially on Germany. French military circles sought not only to recover Alsace and Lorraine and to occupy the Saar but also to detach the Rhineland from Germany. Members of the British Parliament lobbied to increase the reparations Germany was to pay, despite the objections of several farsighted economists, including John Maynard Keynes.

The Versailles treaty, signed on June 28, 1919, met most of these demands. It also stripped Germany of its colonies and imposed severe restrictions on the rebuilding of its army and fleet. In these ways, the peace settlement could be seen as punishing the defeated enemy, as well as reducing its status and strength. Not unnaturally, this caused resentment among the Germans and helped to stimulate the quest for revenge.

At the same time, however, Versailles was imbued with more constructive aims and hopes. In January 1918 the U.S. president, Woodrow Wilson, set out his peace proposals in the "Fourteen Points." The general principles were open covenants openly arrived at, freedom of navigation, equality of trading conditions, the reduction of armaments, and the adjustment of colonial claims. Wilson also proposed "a general association," which became the League of Nations, but his more specific suggestions were concerned less with unity among nations than with national self-determination. His aim, in effect, was to secure justice, peace, and democracy by making the countries of Europe more perfect nation-states.

Territorial readjustments

Among other measures, this involved readjusting Germany's borders. Alsace-Lorraine was duly returned to France and Eupen-Malmédy to Belgium, while Germany also lost territory to the east. But the Versailles and associated settlements went further still in dealing with central

Europe. They broke up the Austro-Hungarian Empire, they created or re-created sovereign states, and they sought to make frontiers coincide with the boundaries between ethnic, linguistic, and cultural groups. This consecration of nationalism proved a highly equivocal legacy; for example, in Northern Ireland or in the German-speaking Sudetenland of Bohemia.

In succession to the Habsburg empire, Austria and Hungary became small, separate, landlocked states. Poland was restored and acquired new territory; so did Greece, Italy, and Romania, which doubled its former size. Czechoslovakia and Yugoslavia came into existence as composite states. Estonia, Latvia, and Lithuania won independence from Russia.

Parallel to the dismemberment of the Austro-Hungarian Empire, a further result of the war was the collapse of the Ottoman Empire. Most of its eastern Mediterranean territory, together with Iraq, was placed under mandate to France and to Britain, which backed a ring of Arab sheikdoms around the Persian Gulf, the Red Sea, and the Indian Ocean. Turkey was reduced to a mere 300,000 square miles. The peace terms initially agreed upon by the Treaty of Sèvres were rejected by the sultan until British troops occupied Istanbul, and even then the National Assembly in Ankara organized resistance. A war with Greece in 1921–22 ended in the Peace of Lausanne, giving Turkey better terms than those decided at Sèvres. Soon, however, the secular sultanate and the religious caliphate were abolished, and Kemal Atatürk became president of a new, secular republic, which, among other Westernizing measures, adopted the Latin alphabet in place of Arabic script.

The drawing of new frontiers could never definitively satisfy those who lived on either side of them, and the problem of minorities became an important factor in the instability that marked Europe after World War I. The new composite state of Czechoslovakia, for instance, included not only industrialized Bohemia, formerly Austrian, but also rustic Slovakia and Ruthenia, formerly Hungarian. Romania similarly comprised both Transylvania, formerly Hungarian, and Bessarabia, formerly Russian. Reconstituted Poland was equally an amalgam, and in 1921, after Józef Piłsudski's campaign against the U.S.S.R., it moved its eastern frontier more than 100 miles beyond the so-called Curzon Line established in 1920. Yugoslavia, finally, was based mainly on Serbia; but it also included Westernized Croatia, formerly Austro-Hungarian, and part of Easternized Macedonia, formerly Turkish, as well as other territories. The rest of Macedonia was now Greek; but an exchange of minorities between Greece and Bulgaria put many Macedonians under Bulgarian rule, sparking off an armed rebellion. Similar turbulence agitated Albania. Altogether, the Balkans became a synonym for violent nationalistic unrest.

Two global developments, moreover, formed an ominous backdrop to Europe's territorial disputes. One was the Russian Revolution of 1917, which inspired a few idealists but mainly aroused fear throughout the rest of Europe lest bolshevism spread westward. The other was the active intervention of the United States, which had entered the war—decisively—in 1917 and played a determinant role in shaping the peace.

THE INTERWAR YEARS

The League of Nations

Hopes in Geneva. Woodrow Wilson's vision of a general association of nations took shape in the League of Nations, founded in 1920. Its basic constitution was the Covenant—Wilson's word, chosen, as he said, "because I am an old Presbyterian." The Covenant was embodied in the Versailles and other peace treaties. The League's institutions, established in Geneva, consisted of an Assembly, in which each member country had a veto and an equal vote, and a smaller Council of four permanent members and four (later six, then nine) temporary members chosen by the Assembly.

The basic principle of the League was collective security, whereby its signatories were pledged both to seek peaceful solutions to disputes and to assist each other against aggression. As such, it was novel and potentially far-reaching; it could have developed into a powerful instrument for peace. It did indeed settle a number of practical disputes—between Finland and Sweden, Albania and Yugoslavia, Poland and Germany, Hungary and Czechoslovakia. It also set up subordinate bodies to deal with particular problems, among them the status of Danzig and the Saar, narcotics, refugees, and leprosy. It was complemented by a Permanent Court of International Justice in The Hague, Neth., and by the International Labor Organization.

Yet the League of Nations disappointed its founders' hopes. From the start it lacked teeth, and most of its members were unwilling to see it develop. It thus became little more than a permanent version of the congresses (of Vienna, etc.) that had founded the old-style Concert of Europe.

Its first weakness was the veto: all its decisions had to be unanimous, or at least unopposed. Secondly, when in March 1920 the U.S. Congress failed to ratify the Versailles treaty by the necessary two-thirds majority, the United States was debarred from joining the League. Nor, at that time, were Germany and Russia among its members. Germany belonged from 1926 to 1933, and the U.S.S.R. from 1934 to 1939. Turkey joined in 1932, but Brazil withdrew in 1926, Japan in 1933, and Italy in 1937.

American suspicion of the League, reflecting general isolationism, centred on Article 10 of the Covenant. This called on member states

> to respect and preserve as against external aggression the territorial integrity and existing political independence of all the Members of the League. In case of any such aggression or in case of any threat or danger of such aggression the Council shall advise upon the means by which this obligation shall be fulfilled.

The means envisaged were known as sanctions—an economic boycott authorized under Article 16 of the Covenant and invoked in October 1935 against Italy for invading Abyssinia. However, as a conciliatory gesture, the League excluded oil, iron, and steel from the boycott, making the sanctions ineffective. Within less than a year they were lifted, and they were not applied at all when Germany sent troops into the Rhineland in 1936.

Nevertheless, the League did witness one effort to go beyond mere cooperation between governments. It proved abortive, but in retrospect it was highly significant. This was the proposal for European unity made by the French statesman Aristide Briand.

When taking office as foreign minister in 1925 he had declared his ambition to establish "a United States of Europe," and on Sept. 9, 1929, he made a speech to the then 27 European members of the League in which he proposed a federal union. Seven months later, on May 1, 1930, he laid before them a closely and cogently argued "Memorandum from the French Government on the Organization of a Regime of European Federal Union." The text was elegantly worded; its actual author was the secretary-general of the French Foreign Ministry, Alexis Léger—better known to readers of poetry under his pen name Saint-John Perse and later a winner of the Nobel Prize for Literature.

Briand's memo on European unity

Briand's proposal evoked "the very real feeling of collective responsibility in the face of the danger that threatens the peace of Europe," and the need to counter Europe's "territorial fragmentation" by a "bond of solidarity which would enable European nations at last to take account of Europe's geographical unity." To this end, Briand proposed a pact establishing a European Conference within the League of Nations, with a permanent political committee and a small secretariat, putting politics before economics in this European community, but nevertheless working toward a "common market" in which "the movement of goods, capital, and people" would be gradually liberalized and simplified. The practical details, Briand suggested, should be worked out by the governments concerned.

Briand's Memorandum was careful to specify that agreement between the European nations must be reached on the basis of "absolute sovereignty and total political independence."

> Is it not the genius of each nation to be able to affirm itself still more consciously by co-operating in the collective effort

within a federal union that fully respects the traditions and characteristics of each of its constituent peoples?

Despite these precautions, the other members of the League did little to implement the French initiative. Except for Bulgaria, Yugoslavia, and (with some reservations) Czechoslovakia, Greece, and Norway, their general response was at best skeptical and at worst politely hostile. None save The Netherlands saw any need to limit or pool national sovereignty. Many—including Denmark, Italy, The Netherlands, Poland, Sweden, Switzerland, and the United Kingdom—expressed fears for the integrity of the League. Several saw no point in setting up new institutions. Some wanted to recruit other European nations such as the U.S.S.R. and Turkey, which were not then members of the League; others insisted on their own world responsibilities, as did the United Kingdom. A large number—understandably, after the Wall Street crash—thought that Europe's really urgent tasks were economic, not political.

Briand defended his paper with vigour, but on Sept. 8, 1930, the European members of the League effectively buried it, with a few rhetorical flowers—"close collaboration," "in full agreement with the League of Nations," "respecting all the principles of the Pact"—by voting to put it on the agenda of the plenary Assembly. All that followed was a series of meetings, which ended with Briand's death in 1932.

Earlier, Briand had worked closely with the German foreign minister Gustav Stresemann, with whom he had negotiated the Locarno Treaties of 1925, confirming, among other things, the new western frontiers of Germany. A fervent nationalist during the war, Stresemann had come to the conclusion that Germany must respect the Versailles treaty, however harsh its provisions, though initially he had hoped to revise it. As a champion of peace (for which he had won the Nobel Prize in 1926), he would surely have supported Briand's federal union plan. But Stresemann died in 1929, and Chancellor Heinrich Brüning of the Catholic Centre Party proved no less negative than most of his colleagues elsewhere. By that time, too, Germany's fragile postwar Weimar Republic was under growing threat of collapse.

The lottery in Weimar. Germany's Weimar Republic was born of defeat, revolution, and civil war. It was plagued by political violence but distinguished by cosmopolitan culture that influenced both Europe and the wider world.

On Oct. 28, 1918, the sailors at the Kiel naval base mutinied, and on November 8 the Independent Socialist Kurt Eisner declared Bavaria a republic. On the following day the chancellor, Prince Maximilian von Baden, resigned in favour of the Social Democrat leader Friedrich Ebert and announced the abdication of the emperor William II. That same day, November 9, the Social Democrat Philipp Scheidemann proclaimed all of Germany a republic. Two days later, on November 11, Germany concluded the armistice that ended World War I.

The new republic was soon under pressure from both left and right. Left-wing socialists and Marxist "Spartacists," led by Karl Liebknecht and Rosa Luxemburg, fomented strikes and founded Workers' and Soldiers' Councils like those in the U.S.S.R., but on Jan. 15, 1919, both revolutionaries were arrested and brutally killed. On the right, meanwhile, ex-officers and others formed the paramilitary Freikorps. In the event, it was from the right that the deadliest challenges came.

Elections to a constitutional convention, or assembly, were held on Jan. 19, 1919. They gave the Social Democrats 163 seats, the Catholic Centre Party 89, and the new and progressive Democratic Party 75; other parties won smaller numbers of seats. These three groups were like-minded enough to form a coalition and powerful enough—for the present—to dominate the new republic. Their rivals on the right were the old conservatives (now called the National People's Party), with 42 seats, and the new People's Party, with 21. On the left, the Independent Socialists had 22 seats.

The National Assembly met on Feb. 6, 1919, at Weimar on the Ilm River. The choice of venue was only partly a tribute to the city's historic associations with Goethe, Schiller, and Herder; the main concern was to avoid the danger of violence in Berlin. Not until the spring of 1920 did the new republic's Parliament (still called the Reichstag, or "Imperial Diet") meet in the German capital. By then, the name Weimar Republic had stuck.

Its constitution, completed on July 31, 1919, was the most modern and democratic imaginable, based on universal suffrage, proportional representation, and referenda. But it was a flimsy cap over a political volcano.

Threats to the moderate coalition

The first sign of trouble, in March 1920, was an attempted monarchist coup d'état. It failed, but the elections that followed in June marked a defeat for the republicans. The centrist Democrats lost almost two-thirds of their strength and the Social Democrats almost half of theirs. The right-wing parties and the left-wing Independent Socialists, plus various splinter groups, made heavy gains. The Weimar coalition no longer had a majority. Within the Parliament, the extremists had triumphed. Outside it, violence was on the increase.

On Aug. 26, 1921, two ex-officers shot and killed Matthias Erzberger, a Catholic Centre Party deputy who had negotiated the peace terms. On June 24, 1922, three right-wing students shot dead Walther Rathenau, the newly appointed foreign minister, who was Jewish. On Nov. 8–9, 1923, an extremist group staged an abortive *putsch* in Munich. The conspirators included Hermann Göring and Adolf Hitler.

Racked by economic problems, shaken by internal crises and shifting alliances, reviled by the far left and the far right, successive centrist governments struggled ahead for another 10 years. Although politically precarious, the Weimar Republic nonetheless witnessed and helped to foster an extraordinary explosion of creative talent, notably in the arts.

Wassily Kandinsky and Max Ernst in painting, Bruno Walter in music, Bertolt Brecht and Max Reinhardt in the theatre, Walter Gropius in architecture, Albert Einstein in physics, Erwin Panofsky in art history, Ernst Cassirer in philosophy, Paul Tillich in theology, Wolfgang Köhler in psychology, Fritz Lang in films—all these became household names, partly because every one of them took refuge abroad after Hitler came to power in 1933.

All, in their various ways, were part of the cosmopolitan "Modern movement" that pervaded the whole of Europe. Kandinsky was a typical example. Born in Russia, he learned a great deal from French Fauves such as André Derain and Henri Matisse, then settled in Munich, where he developed his own characteristic style. German Expressionist theatre and cinema, likewise, drew inspiration from abroad, in particular from Henrik Ibsen and August Strindberg. Germany was equally influenced by Austrians: Sigmund Freud in psychiatry, Hugo von Hofmannsthal and Arthur Schnitzler in the theatre, and Karl Kraus in the press. In architecture the clean, functional lines of Gropius' Bauhaus school found imitators throughout Europe.

Like all such phenomena, the Modern movement was not wholly novel. Many of its practitioners and their artifacts had predated or coincided with World War I. Even Filippo Tommaso Marinetti's Futurism, so dominant in 1920s Italy, was a relic of the prewar past.

But the mood after 1918 was no longer so euphoric as at the beginning of the century. Before the war, the French novelist André Gide and the German poet Rainer Maria Rilke had exchanged letters in leisurely French like two survivors from the 18th century. After it, following a six-year silence, Rilke wrote of "the crumbling of a world," and both complained of the complications caused by passports and frontier formalities, looking back nostalgically to the carefree "journeys of long ago."

The postwar world, as seen by writers and other artists, had the fragmentary, disillusioned quality of T.S. Eliot's *The Waste Land*, published in 1922. It was self-conscious and introspective, as in Luigi Pirandello's 1921 play *Six Characters in Search of an Author*. It was more open to the unconscious, as in Dada and Surrealism. It was more aware of man's dark fears and instincts, as in Franz Kafka's *The Trial* (1925) and *The Castle* (1926). It was more responsive to the appeal of "the primitive," whether

in African sculpture or in jazz—the quintessential art of the 1920s, which also influenced mainstream music, notably in the Austrian composer Ernst Krenek's 1927 opera *Jonny spielt auf* ("Johnny Strikes up the Band").

No less pervasive, however, was the brittle hedonism typified by the gossip-column antics of the "Bright Young Things." They were not wholly isolated. Already in 1918 Thomas Mann had published his *Reflections by an Unpolitical Man;* this was a mental label thankfully worn by many who, after the rigours of war, were eager to pursue private happiness, whether in metropolitan society or in placid suburbia. The Europe of Weimar also was the Europe of the detective story and the crossword puzzle. Both were analgesics at a time of political uncertainty and economic disquiet.

The impact of the slump. Economically, Europe emerged from World War I much weakened, partly by the purchases that had had to be made in the United States. Even in 1914 the United States had been the world's leading economic power. By 1918 profits had enabled it to invest more than $9 billion abroad, compared with $2.5 billion before the war. The Allies, meanwhile, had used up much of the capital they had invested in the United States and had accumulated large public debts, many of them to the U.S. Treasury.

American financial dominance and European debt overshadowed economic relations in the first decade after the war. The debts included those owed by the Allies to each other, especially to Britain, as well as those owed, especially by Britain, to the United States. A third baneful factor was reparations, the financial penalties imposed on Germany by the Treaty of Versailles.

German war reparations

Keynes described reparations as morally detestable, politically foolish, and economically nonsensical. Winston Churchill called them "a sad story of complicated idiocy." Essentially, they meant demanding from Germany either goods—which would have dislocated industry in the recipient countries—or money. This the Germans could obtain only by contracting vast and almost unrepayable loans in the United States—to whom the European recipients of reparations promptly returned much of the cash in an effort to settle their own transatlantic debts.

In April 1921 the Allied Reparations Committee set Germany's reparations bill at 132 billion gold marks, to be increased later if the Germans proved able to pay more. The first installment of one billion gold marks was due by the end of May.

Understandably resentful, the Germans wavered between two possible responses: refusal to pay, as urged by ultranationalists and some industrialists, and the so-called *Erfüllungspolitik,* or "policy of fulfillment," advocated by Rathenau and Stresemann. They proposed to meet initial demands for reparations so as to reestablish trust and then negotiate for better terms. This was the policy adopted by the Weimar Republic.

Even so, Germany paid the first tranche only in August 1921, in response to a threat to occupy the Ruhr, and the money had to come from a bank loan raised in London. Thereafter, it paid in kind but not in cash, until at the beginning of 1923 it announced that payments must cease. The French and the Belgians, backed by Italy but opposed by the United States and Britain, thereupon occupied the whole of the Ruhr.

With the German government's connivance, Ruhr industrialists and workers brought production to a virtual halt, and the Treasury printed a reckless flood of paper money. By 1924 the mark was almost worthless, enriching speculators and owners of real property but ruining rentier savers and others on fixed incomes. This removed an important stabilizer from German society, making it all the easier for extremism to triumph in the Nazi victory 10 years later.

For the moment, however, the Allies formed a committee of financial experts, chaired by the American Charles G. Dawes, to find a lasting solution to the reparations problem. It proposed, and the governments accepted, a two-year moratorium, the return of the Ruhr to Germany, a foreign loan of 800 million marks, and a new rate for reparation payments: 1–2.5 billion gold marks annually, which continued for five years. In 1929 a further committee, chaired by Owen D. Young, revised the Dawes Plan. Germany was to have a new loan of 1.2 billion marks and to spread reparations over the next 59 years. Although the German Parliament and people (by referendum) reluctantly agreed to the Young Plan, reparations finally ceased in 1932.

Germany's was an extreme case, but it was not the only European country to suffer after World War I. The Allies also experienced inflation and were saddled with debts. While the United States was willing in the long run to write off the political debts of reparations, it would not do the same with the commercial debts contracted by Britain, Italy, and France: one by one, they had to sign agreements to pay.

Despite these obligations, Europe in the 1920s enjoyed a modicum of the economic growth that was so rapid and spectacular in the United States. In 1913, Britain's income had been £2.021 billion. By 1921, it had fallen to £1.804 billion; but by 1929 it had risen again, this time to £2.319 billion. The corresponding figures for France (in 1938 francs) were 328 billion, 250 billion, and 453 billion. Even Germany, whose 1914 income had been 45.7 billion gold marks, had recovered enough by 1931 to be earning 57.5 billion.

Yet postwar prosperity was precarious. The American boom was a speculative affair. Fueled by optimism, production was soaring. To shift the accumulating goods, customers were urged to buy on credit or to borrow from the banks, which thereby earned large profits. The stock market was riding high. But at any sign of a credit squeeze or a loss of confidence, everything was likely to collapse. Demand would fall, goods would pile up, and prices would plummet. This was precisely what happened on "Black Tuesday," Oct. 24, 1929, the day of the Wall Street crash.

Effects of the Wall Street crash

Its first foreign victims were in Latin America, which was dependent on the American market for selling raw materials. Europe was not affected immediately; American loans and investments there dwindled only slowly. By 1931, however, the flow of capital had virtually ceased, and direct investment dried up in the following year. Worse still, to pay their own debts, Americans repatriated huge sums of money. Germany, Austria, and Britain were the hardest hit. Between the end of May and the middle of July in 1931, the German central bank, the Reichsbank, lost $2 billion in gold and foreign currency. To compound Europe's problems, on June 17, 1930, the United States had imposed the protective Smoot-Hawley Tariff, replacing average import duties of 26 percent with the prohibitive average level of 50 percent.

The combined results were catastrophic. Highly respected banks failed, first among them the great Kreditanstalt of Vienna, which collapsed in May 1931. The Bank of England, at that time, was losing gold at the rate of £2.5 million a day. Everywhere, industrial production fell: by 40 percent in Germany, 14 percent in Britain, and 29 percent in France.

On June 20, 1931, U.S. President Herbert Hoover announced a year's moratorium on all government debts. When it expired in June 1932, the secretary of state, Henry Stimson, proposed a year's extension, but Hoover refused. The Europeans had meanwhile agreed to cancel their claims on German reparations but not to ratify this decision unless the United States wrote off their war debts. The Americans, seeing this as a European conspiracy, demanded continued payment. At this, all the European nations except Finland dug their heels in, exacerbating U.S. isolationism and making a global solution of the crisis still more unlikely.

In June 1933, nevertheless, a World Economic Conference met in London. Hoover's successor as president, Franklin D. Roosevelt, made his secretary of state, Cordell Hull, the head of the U.S. delegation. Hull was a free-trader, but in July 1933 Roosevelt sent a message to the conference insisting that its main concern must be monetary exchanges, and in January 1934 the United States passed the Johnson Act, forbidding even private loans to countries that had not paid their war debts.

So there was no global solution: it was every man for

European responses to the Great Depression

himself. Some European countries—Germany in 1930–32, France until 1936—responded by deflation; they maintained the external value of their currencies but reduced their export prices by cutting wages and costs. The result was social unrest. In Germany, Chancellor Brüning's 1930 decrees of the dissolution of the Reichstag and government by presidential order led to 107 Nazis and 77 Communists being elected to Parliament that September. In France, Pierre Laval's decrees led to the 1936 success of the left-wing Popular Front.

Other countries took to devaluation, leaving the gold standard to which Belgium, France, Italy, The Netherlands, and Switzerland still clung from 1931 to 1935. Britain devalued in September 1931, the United States in April 1933, and France in September 1936. This had the effect of making exports cheaper, but since it made imports more expensive it worked only if they could be discouraged by high tariffs (as in the United States) or if the country in question had access to cheap raw materials (as in Britain's system of imperial preference).

A third option was to impose exchange controls to cut the economy off from world markets. This was the solution adopted by Germany in 1932 and by most of central Europe and the Balkans. It had the effect of creating German hegemony, since those central European and Balkan countries that needed to sell to the large German market were unable to repatriate their earnings and had to buy German goods. In 1932 Germany saw exchange controls and their effects as a temporary expedient. For Adolf Hitler and the Nazi party, however, they became part of a settled and sinister policy.

The trappings of dictatorship. Totalitarian dictatorship was a phenomenon first localized in 20th-century Europe. A number of developments made it possible. Since the 19th century the machine gun had greatly facilitated drastic crowd control. Public address systems, radio, and, later, television made it easy for an individual orator to move a multitude. Films offered new scope for propaganda. Psychology and pharmaceuticals lent themselves to brainwashing. Miniature cameras and electronic listening devices simplified surveillance. Heavy artillery, aircraft, and fast armoured vehicles provided the means for waging a *Blitzkrieg,* or "lightning war." Bullies and brutality, of course, there had always been.

The European dictatorships were far from identical. They differed in their historical roots, their social contexts, their ideologies, and their trappings. But they bore a family resemblance. Political analysis may underplay it; to their victims, it was all too obvious.

Europe's first practical dictatorship was established in Russia by the Bolshevik Revolution of 1917. Its emblem, the hammer and sickle, represented physical labour in factory or field; there was no symbol for the scientist, the statesman, or the scholar. The aims of the revolution—liquidating the capitalist economic system, increasing public wealth, raising the material and cultural standard of working people—had wide appeal. But in its concern to industrialize and modernize a huge, backward union of republics with a long cultural legacy of tsarist domination that had been replaced by a centralizing socialist ideology, it relied on a one-party state, heavy censorship, the suppression of individual liberty, and the murder of awkward opponents. Theoretically, it foresaw "the withering away of the state." For the time being, it embodied "the dictatorship of the proletariat"—or rather of a single leader, first Vladimir Ilich Lenin, then Joseph Stalin.

Two years after the Russian Revolution, in 1919, Benito Mussolini founded the fascist party in Italy. Its emblem, the fasces (a bundle of rods with an axe in the centre), was a symbol of state power adopted from ancient Rome.

European fascism

Explicitly anticommunist, it was as opposed to the withering away of the state as it was to individualistic liberalism. "For the Fascist," wrote Mussolini, "everything is the State." His own regime, partially established in 1924 and completed in 1928–29, had its bullyboys and castor-oil torture, its murders and aggressive wars. But, for sociological and cultural, as well as political, reasons, it was both less systematic and less brutal than some other European dictatorships. Italy had a long tradition of regional diversity that resisted uniformity, and Italian society was permeated—in complex, sometimes contradictory ways—by the ubiquitous influence of the Roman Catholic church.

Forms of fascism took root in other Latin countries. In Spain in 1923 General Miguel Primo de Rivera seized power with the approval of the king. He dissolved Parliament, imprisoned democratic leaders, suspended trial by jury, censored the press, and placed the country under martial law. He tried to establish a fully fascist regime based on "Country, Religion, and the Monarchy," but he met resistance from students and workers and abandoned the attempt in 1925, although he remained prime minister until 1930. In 1931 a republic was proclaimed, headed by a provisional government of republicans and socialists.

Meanwhile, in neighbouring Portugal, António de Oliveira Salazar, a professor of economics, had been made finance minister after a military coup d'état in 1926; and, although he had resigned soon afterward, he had been recalled in 1928. After reorganizing the Portuguese budget, in 1932 he was offered the premiership. His conception of what he called the "Estado Novo," or "New State," was corporatist and fascist. Its authoritarian constitution, endorsed by plebiscite in 1933, allowed only one political party, the National Union (União Nacional).

In 1936 a general election in Spain gave a clear majority to the left. On May 10, Manuel Azaña, the Popular Front leader, was elected president, but two months later a group of army officers led by General Francisco Franco staged a fascist revolt. Supplied with arms, air power, and "volunteers" by Mussolini and Hitler, Franco's forces won the ensuing Spanish Civil War—although it dragged on until 1939, when the U.S.S.R. finally cut off the aid it had given to the Republican government. The French and British governments pursued a policy of nonintervention, although an International Brigade of private volunteers fought alongside the Republicans. One significant feature of the Spanish Civil War was its use by Nazi pilots as a training ground for the dive-bombing tactics they later employed in World War II.

Nazi Germany, in fact, was Europe's most elaborately developed dictatorship. Characteristically, Hitler took great care with the design of its emblem, a black swastika in a white circle on a red background; as iconography, it has long survived its regime. The swastika, originally the obverse of the Nazi version, was an Eastern mystic symbol brought into Europe in the 6th century—and Nazi ideology was no less mystical. It differed from fascism in at least two respects. It regarded the state as a means, rather than an end in itself; and the end it envisaged was the supremacy of what Hitler believed to be "the Aryan master race." The final result—Hitler's so-called Final Solution—was the systematic slaughter of at least six million Jews.

Born in Austria, Hitler had fought in World War I in the Bavarian infantry, twice winning the Iron Cross. In September 1919, six months after Mussolini founded the Italian fascist party, Hitler joined a German nationalist group that took the name of National Socialist German Workers' Party, derisively nicknamed "Nazi." Its policies included anti-Semitism and fierce opposition to the Treaty of Versailles. After his abortive Munich coup in 1923, Hitler was sentenced to five years' imprisonment, of which he served nine months. While in prison, he wrote his autobiographical manifesto, *Mein Kampf.*

Rise of Adolf Hitler

In 1930, with 107 seats, the Nazis became the second largest party in Parliament. On Jan. 30, 1933, after three ineffectual chancellors, President Paul von Hindenburg appointed Hitler to the post, believing that the vice-chancellor, Franz von Papen, would counterbalance any Nazi excess.

Four weeks later the Reichstag building in Berlin was gutted by a fire probably started by a foolish young Dutchman, but certainly exploited by the Nazis as evidence of an alleged communist plot. Hitler used the excuse to enact decrees that gave his party totalitarian powers. In the following June he eliminated most potential rivals, and when Hindenburg died on Aug. 2, 1934, Hitler was proclaimed *Führer,* or leader of the German Reich.

Hitler's foreign policy triumphs followed: the reoccupation of the Rhineland and the alliance with Mussolini

in 1936; the *Anschluss* ("union") with Austria and the occupation of Czechoslovakia in 1938–39; and in 1939 the German-Soviet Nonaggression Pact. Until Hitler's invasion of Poland in September of that year, it sometimes seemed as if Europe's democracies could only look on, prevaricate, and tremble.

The Phony Peace. The early months of World War II, marked by no major hostilities, came to be known as "the Phony War." The 1930s, marked by war in Spain and the fear of war throughout Europe, might as aptly be called "the Phony Peace."

Economically, that decade saw a gradual revival of prosperity in most of Europe. For the middle classes in some countries, indeed, it was a slightly hollow golden age. Many could still afford servants, often drawn from the ranks of unmarried girls from poor families with few skills to sell. "Ribbon development" of suburbs was providing new houses on the cleaner outskirts of cities, served by expanding urban transport systems. Every suburb had one or more palatial cinemas showing talking pictures, some of them even in colour. Gramophones and records were improving their quality, radio sets were growing more compact and versatile, and, toward the end of the decade, television began. Cheaper automobiles were appearing on the market, telephones and refrigerators were becoming general, and some homes began to boast washing machines. Air travel was still a rarity but was no longer unheard of. The cheap franc made France a playground for tourists from countries with harder currencies.

For those less privileged, daily life was far less benign. Deference was still deeply ingrained in European society. The humbler classes dressed differently, ate differently, and spoke differently; they even walked and stood differently. They certainly had different homes, often lacking a bathroom or an indoor lavatory. Unemployment was still widespread. In Britain, in the Tyneside town of Jarrow, starting point of the 1936 protest march to Westminster, almost 70 percent of the work force was out of a job. Those in work still faced long hours; dirty, noisy, and dangerous conditions; and monotonous, repetitive assembly-line tasks. Some of the workers were women, but, despite their "liberation" during World War I, many had returned to domesticity, which to some seemed drudgery. Young people had yet to acquire the affluence that later gave them such independence and self-assurance as an economic and cultural group.

Political reactions to the Depression

Beneath the placid surface, moreover, there were undercurrents of unease. On the right, especially in France and Germany, there was still much fear of bolshevism. Some, for this reason, saw merits in Mussolini, while a few were attracted by Hitler. On the left, conversely, many admired the U.S.S.R.—although some, such as the French writer André Gide, changed their minds when they had seen it. But left, right, and centre in most of the democracies had one thing in common, though they differed radically about how to deal with it. What they shared was a growing fear of war. Having fought and won, with American help, "the war to end war," were they now to face the same peril all over again?

This fear became acute toward the end of the decade, as Hitler's ambitions grew more and more plain. But underlying it was a broader, deeper, and less specific disquiet, especially in continental Europe.

In 1918 the German philosopher of history Oswald Spengler published *Der Untergang des Abendlandes,* translated in 1926–28 as *The Decline of the West.* In 1920 the French geographer Albert Demangeon produced *The Decline of Europe.* In 1927 Julien Benda published his classic study *The Great Betrayal,* and in 1930 José Ortega y Gasset produced *The Revolt of the Masses.* All these works—and many others—evoked what the Dutch historian Johan Huizinga called, in the title of a book published in 1928, *The Crisis of Civilisation.* That same year, coincidentally, saw Renê Guenon's *The Crisis of the Modern World.* Similar concerns were voiced in Britain almost a decade later, when the French-born Roman Catholic writer Hilaire Belloc published *The Crisis of our Civilisation.*

Many such writers were pessimistic. Paul Valéry, in *Glimpses of the Modern World* (1931), warned Europeans against abandoning intellectual discipline and embracing chauvinism, fanaticism, and war. Thomas Mann, in *Warning Europe* (1938), asked: "Has European humanism become incapable of resurrection?" "For the moment," wrote Carl J. Burckhardt, "it . . . seems that the world will be destroyed before one of the great nations of Europe gives up its demand for supremacy."

At Munich in September 1938 the British prime minister Neville Chamberlain and his French counterpart Édouard Daladier bought time with "appeasement"—betraying Czechoslovakia and handing the Sudetenland to Hitler. Millions cheered the empty pledge they brought back with them: "Peace for our time." Within 11 months Hitler had invaded Poland and World War II had begun.

THE BLAST OF WORLD WAR II

World War II was the most destructive war in history. Estimates of those killed vary from 50 million to 64 million—about as many as the entire population of Britain or France. The total for Europe alone was 15 million to 20 million—more than twice as many as in World War I. At least 6 million, not all of them Jews or Gypsies, died in Hitler's extermination camps. Nor were the Germans themselves spared. By 1945, in a population of some 70 million, there were 7 million more German women than men.

One after another, most of the countries in continental Europe had been invaded and occupied: Austria, Czechoslovakia, Albania, Poland, Finland, Denmark, Norway, Belgium, The Netherlands, Luxembourg, France, Lithuania, Latvia, Estonia, Romania, Bulgaria, Hungary, Greece, Yugoslavia, and the U.S.S.R. and then, when the tide turned, Italy and Germany. Many countries had been fought over twice.

The resulting devastation had turned much of Europe into a moonscape: cities laid waste or consumed by fire storms, the countryside charred and blackened, roads pitted with shell holes or bomb craters, railways out of action, bridges destroyed or truncated, harbours filled with sunken, listing ships. "Berlin," said General Lucius D. Clay, the deputy military governor in the U.S. zone of postwar Germany, "was like a city of the dead."

Casualties of the war

Between 1939 and 1945, moreover, at least 60 million European civilians had been uprooted from their homes; 27 million had left their own countries or been driven out by force. Four and a half million had been deported by the Nazis for forced labour; many thousands more had been sent to Siberia by the Russians. When the war ended, 2.5 million Poles and Czechs were transferred to the U.S.S.R., and more than 12 million Germans fled or were expelled from eastern Europe. At one period in 1945, 40,000 refugees a week poured into northwestern Germany.

Death, destruction, and mass displacements—all had demonstrated how fragile and vulnerable Europe's proud nations had become. In most earlier conflicts the state's defenses had been its frontiers or its front line: its armies had been a carapace protecting the civilians within. Now, even more than in World War I, this was no longer so. Air raids, rockets, mass conscription, blitzkrieg invasion, commando raids, parachute drops, Resistance sabotage, and guerrilla warfare had put everyone, as the phrase went, "in the front line." More accurately, national frontiers had shown how flimsy they were, and the "front line" metaphor had lost its force. Even the distinction between civilians and soldiers had become blurred. Civilians had fought in Resistance circuits—and been shot, sometimes as hostages, and when the Allies or the Axis practiced area bombing, civilians were the main victims. The most extreme instances were the atomic bombs dropped on Hiroshima and Nagasaki in Japan. They not only ignored the civilian-military distinction; they utterly transformed the nature of war.

Hitler's death camps, likewise, made World War II unique. The appalling product of spurious science, evil fanaticism, blind bureaucratic obedience, sadistic perversion, and pedantic callousness, they left an unhealing wound. They reminded humanity of the depths to which human beings can sink and of the vital need to expunge

racism of all kinds—including the reflex, understandable at the time, of regarding the Germans as solely capable of committing Nazi-type crimes.

The Nürnberg trials were a further unique feature of World War II. By arraigning and punishing major surviving Nazi leaders, they undoubtedly supplied a salutary form of catharsis, if nothing else. They proved beyond doubt the wickedness of Hitler's regime; at one point, when films of the death camps were shown, they actually sickened and shamed the defendants. In some eyes, however, the trials were somewhat tainted. Although scrupulously conducted, they smacked slightly of show trials, with the victorious Allies playing both prosecutor and judge. The charges included not only war crimes, of which many of the accused were manifestly guilty, but also "waging aggressive war"—a novel addition to the statute book. Finally, a number of war criminals certainly slipped through the Nürnberg net. The overall intention, however, was surely honourable: to establish once and for all that international affairs were not immune from ethical considerations and that international law—unlike the League of Nations—was growing teeth.

The division of Europe into East and West

In two further respects, World War II left a lasting mark on Europe. The first and most obvious was its division between East and West. Both U.S. and Soviet troops, from opposite directions, had helped to liberate Europe, and on April 25, 1945, they met on the Elbe River. They toasted each other and posed for the photographers; then the Soviets dug themselves into new defensive positions, still facing west.

It was not a confrontation, but it was symbolic. Stalin had long made clear that he sought to recover the three Baltic republics of Latvia, Lithuania, and Estonia, as well as the part of Poland that the Poles had seized after Versailles. He also expected a free hand in exerting influence on the rest of eastern Europe. At a meeting in Moscow in October 1944, Churchill had largely conceded this principle, proposing 90 percent Soviet influence in Romania, 90 percent British influence in Greece, 75 percent Soviet influence in Bulgaria, and a 50–50 split in Yugoslavia and Hungary. Cynical as this might seem, it was a tacit recognition of strategic and military facts. Similar considerations determined the East-West zonal division of Germany, which endured in the form of two German republics until their reunification in October 1990.

The fact that the U.S.S.R. and the United States now faced each other in Europe along the so-called "Iron Curtain" denounced by Churchill in his Fulton, Mo., speech on March 5, 1946, dramatized Europe's final legacy from World War II. This was a drastic reduction in wealth, status, and power.

In financial terms, World War II had cost more than the combined total of all European wars since the Middle Ages. Even Britain, which had been spared invasion, had been transformed from the world's biggest creditor to the world's biggest debtor, and much of continental Europe was obliged to continue living on credit and aid. Economically, all Europe's once great powers were dwarfed by the world's superpowers. Their status was diminished still further when their remaining colonies were freed.



Europe 1920–38 (top) and 1945–90 (bottom).

POSTWAR EUROPE

Planning the peace. International planning for peace after World War II took place on a world scale. Within five years, in an extraordinary burst of energy and imagination, statesmen endowed the world with almost all its existing network of global institutions: the United Nations (UN), the Food and Agriculture Organization (FAO), the International Monetary Fund (the IMF), the International Bank for Reconstruction and Development (the IBRD, or World Bank), the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United Nations International Children's Emergency Fund (UNICEF), the International Court of Justice, the General Agreement on Tariffs and Trade (GATT), the International Refugee Organization (IRO), the World Health Organization (WHO), the United Nations Relief and Works Agency (UNRWA), and the International Confederation of Free Trade Unions (ICFTU). Some of these, in particular the UN, were to reveal limitations. But they embodied serious efforts to replace outdated national and bilateral diplomacy with permanent multilateral institutions.

Domestically, many people's first instinct after World War II was to return to normal: to restore law and order after the euphoric anarchy of liberation; to repatriate prisoners and demobilize soldiers; to reopen the bombed Teatro alla Scala, Milan, and have Arturo Toscanini conduct there again; and to bring back long dresses with Christian Dior's "New Look." At the same time, however, there was deep eagerness for change. Even more than World War I, World War II had been a democratic war, fought against dictatorship as much as against aggression. Like many wars, it had brought forth military and other leaders from the rank and file. For many the aim was to inaugurate a new and more just society within nation-states that were pledged to work together for peace. "From Resistance to Revolution" was the masthead slogan of *Combat*, the left-wing French Resistance newspaper founded in 1941 but after the war edited as a Paris daily by the novelist Albert Camus. The words could well have been endorsed by others, in particular the radical Action Party in Italy and many socialists there and elsewhere.

No less innovative, if less radical, were the Christian Democrat parties springing up or being revived: the Christian Democrats in Italy, the Christian Democratic Union in Germany, the Dutch People's Movement in The Netherlands, the Popular Republican Movement in France. At that time, most such Roman Catholic parties had a more left-of-centre tone than was later the case.

Britain had no Christian Democrat party, and its Labour Party had less in common with continental socialist ideology than with nonconformism and the trade union movement. Yet the British people shared the general impatience

for change, as they showed when they voted in large numbers for Labour in the 1945 general election, roundly defeating the Conservatives under Winston Churchill, who had led the country so memorably during the war.

In its election manifesto, the Labour Party proposed a program of nationalization of the Bank of England, of fuel and power, of iron and steel, and of inland waterways. It endorsed the Education Act already steered through by the moderate Conservative R.A. Butler. It proposed a national health service and a social security system, and it called for physical controls to allocate raw materials, limit food prices, provide new homes, and direct the location of industry.

The beginnings of the welfare state

Similar reforms were envisaged throughout western Europe. They embraced more equality, fairer shares, and better social conditions—full employment, higher wages, fairer taxes, more trade union rights, antitrust provisions, government-funded social security, and (where necessary) land reform. Such measures also implied far more central control of the economy.

"Planning" was now a common objective. In Italy it was the responsibility of the Institute of Industrial Reconstruction. In Britain the government maintained the machinery of statutory controls that it had used in wartime. In Germany the banks played a major role in forecasting, steering, and assisting investment. But in France it was the extraordinary Jean Monnet who made planning a concerted national effort rather than a set of directives from above.

Between the wars Monnet had been deputy secretary-general of the League of Nations, a private banker, and a negotiator for the French government. In the United States during World War II he had helped to spur Roosevelt's Victory Program of aircraft for the Allies. Subsequently, in Algiers, he had helped to reconcile General Charles de Gaulle with his American-backed rival General Henri Giraud. It was to de Gaulle, who shortly became premier of France, that Monnet proposed a planning commissariat, attached only to the prime minister's office and bringing together for the first time in France industrialists, labour unions, and senior civil servants to discuss production targets, supplies, bottlenecks, and urgent action in key sectors of the economy. Revolutionary at the time, the plan was highly successful and was soon imitated elsewhere.

National planning alone, however, could not solve Europe's problems. Joint action was needed, as was help from the United States. In 1947, two years after the end of the war, many Europeans were still leading a Spartan existence. Everywhere, food continued to be rationed. Dimmed lights, brownouts, and power cuts were still common. A hard winter and waves of strikes added to the general misery. Underlying it was the stark fact that the countries of Europe were in serious financial trouble.

They had long been living on handouts. By October 1945 the United States had advanced some $46 billion in nonrepayable "lend-lease" loans. When the war ended, so did lend-lease—to be replaced by huge stopgap loans on ordinary terms. Britain received $3.75 billion, but only on condition that it make sterling freely convertible. As soon as it did, there was a run on the pound. The entire loan, it was reckoned, would have melted away in two and a half months if Britain had not suspended convertibility. As it was, a third of the credit was wiped out by price increases in the United States.

Britain, in fact, was overextended. In 1946 it had spent $60 million to help feed the German people, and it still had one and a half million troops trying to police the globe. Already, on Feb. 21, 1947, Britain had warned the United States that it would soon have to cancel economic and military aid to Greece and Turkey. It was this message that triggered a rescue operation for the whole of western Europe.

The United States to the rescue. Greece and Turkey, in the Cold War conditions of 1947, were strategically vital and highly vulnerable Western outposts on the southern flank of the U.S.S.R. and its satellite states. Turkey was especially exposed. In Greece, the mainly communist National Liberation Front (EAM) had failed in its violent bid for power, but guerrilla units were still fighting in the Pindus Mountains and the Peloponnese, and the Greek economy was near collapse.

The news that Britain was to pull out of the Balkans horrified Washington. Dean Acheson, the under secretary of state, called the British messages "shockers." With George Marshall, the secretary of state, he lost no time in tackling the problem. After conferring with them, President Harry S. Truman called in the Congressional leaders—and managed to win to his cause the influential Republican senator Arthur H. Vandenberg, theretofore a notorious isolationist. With his support secured, Acheson felt able to quote to the British ambassador the motto of the Seabees: "We do the difficult at once; the impossible takes a little longer."

The Truman Doctrine and the Marshall Plan

On March 12, 1947, less than three weeks after Britain's plea for help, Truman announced to Congress what came to be called the Truman Doctrine: U.S. support for free peoples against armed subjugation, primarily through economic and financial aid. By May 22 he had been empowered to sign the Greek-Turkish Aid Act.

Reports from Europe, however, showed that other countries were equally in need of American help. On June 5, 1947, Marshall gave a 10-minute commencement address at Harvard University and thereby launched the Marshall Plan. This and the Truman Doctrine, Truman remarked later, were "two halves of the same walnut." Marshall told his audience,

> Europe's requirements for the next three or four years of foreign food and other essential products are so much greater than her present ability to pay that she must have substantial additional help.

Without it, the economic, social, and political outcome could be "very grave."

> Aside from the demoralizing effect on the world at large and the possibilities of disturbances arising as a result of the desperation of the people concerned, the consequences to the economy of the United States should be apparent to all. It is logical that the United States should do whatever it is able to do to assist in the return of normal economic health in the world, without which there can be no political stability and no assured peace.

Marshall added three conditions. First, aid must be systematic, not piecemeal. Second, the countries of Europe must work out their needs and plans together. Third, public opinion must endorse the policy.

Hearing the news of Marshall's speech and a commentary by a specially briefed British journalist, British foreign secretary Ernest Bevin "grabbed the proposals," as he said later, "with both hands." With French foreign minister Georges Bidault, he invited their colleague from the U.S.S.R., Vyacheslav Mikhaylovich Molotov, to join in a collective response to the Marshall offer. Molotov refused, attacking the plan as a violation of sovereignty. Later the U.S.S.R. prevented Czechoslovakia from taking it up.

So it was that the Marshall Plan was confined to western Europe. On July 12, 1947, the representatives of 16 nations met in Paris: Austria, Belgium, Denmark, France, Greece, Iceland, Ireland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Sweden, Switzerland, Turkey, and the United Kingdom. Four days later they set up a temporary Committee of European Economic Co-operation under Sir Oliver Franks. By the third week in September it had produced a draft four-year recovery plan, which was subsequently much revised. Under powerful U.S. pressure, the Europeans reluctantly agreed to establish a permanent body in place of the temporary committee. It was finally inaugurated as the Organisation for European Economic Co-operation (OEEC) on April 16, 1948.

By then the U.S. Congress had approved the European Recovery Program, and Truman had appointed Paul Hoffman to administer it. Within two weeks of his appointment, the freighter *John H. Quick* sailed for Europe from Galveston, Texas, with 9,000 tons of wheat. It was the first of many, carrying every kind of commodity from spiced ham to tractors, from powdered eggs to machine tools. Within Europe, Marshall aid made possible some spectacular projects. They ranged from land reclamation in Italy and The Netherlands to a dam in Austria harnessing water power from melting glaciers. In all, the European Recovery Program brought Europe grants and credits to-

taling $13.15 billion—5 percent of the national income of the United States. At the same time, private relief parcels amounted to over $500 million—more than $3.00, on average, from every American man, woman, and child.

The United States' timely generosity saved Europe from imminent economic ruin and laid firm foundations for later economic growth. By 1950 trade within western Europe had recovered to its prewar volume, two years ahead of expectations; and by 1951 European industrial output was 43 percent greater than before the war. U.S. insistence on a coordinated approach to recovery supplied the incentive and the institutions for permanent mutual consultations; in the process, the OEEC gradually reduced the quantitative and monetary barriers that had hamstrung intra-European trade. It failed, however, to remove tariffs. U.S. pressure for a European customs union eventually came to nothing; although willing to consult and cooperate, Europeans were not yet ready for economic integration, still less political union.

This made difficult a relationship of equals between European countries and the United States. But, short of that, the Marshall Plan did lead to much closer transatlantic ties. Under W. Averell Harriman, its Paris-based chief representative, U.S. experts worked throughout Europe. "They swooped down here," said one German businessman, "like birds on a field." By 1952 the U.S. embassy in Paris was responsible for 2,500 U.S. officials, plus 5,000 family members. Within a decade, 40,000 private American businessmen had settled in Europe, working for 3,000 American companies, whose European investments had quadrupled in that time.

War and peace had brought Europeans and Americans closer together than at any time since the mass migrations from the Old World to the New. Their mutual relations were complex and ambivalent: a blend of European gratitude, envy, and slight resentment combined with American impatience, fascination, and missionary zeal. As time went on, some Europeans complained of "Americanization"; what this often meant was merely that innovations had reached the United States first. But, for all their differences, Americans and western Europeans had one great common commitment—to a free and democratic way of life, which in eastern Europe had been progressively suppressed.

A climate of fear. By the time that Roosevelt, Churchill, and Stalin had held their Yalta Conference in February 1945, Europe was already divided between East and West; Yalta, therefore, was not to blame for the division. On the contrary, it could in theory have reunited Europe, since all three powers had pledged themselves to help any liberated or former Axis satellite state form an interim government broadly representing all democratic elements, followed as soon as possible by free elections. The Western Allies kept their Yalta promise; Stalin did not.

The spread of communism in eastern Europe

One after another, Stalin subjected all but two of the eastern European countries to a similar takeover process. It was described frankly, in retrospect, in a textbook published between 1948 and 1950 by the Communist Party of Czechoslovakia: *How Parliament Can Play a Revolutionary Part in the Transition to Socialism and the Role of the Popular Masses.* First, communist ministers were imposed upon the existing coalition government, if possible in key posts such as the Ministry of the Interior. Then, the party gradually established or infiltrated power centres outside parliament; for instance, by arming the proletariat, setting up action committees, or expanding the secret police. This would create "a pincer movement operating from above and below." The end product was an antidemocratic coup; even if the bourgeoisie still retained some support in the country, a short period of "people's democratic government" would soon achieve "the disintegration of the political army upon which the bourgeoisie could formerly count."

The exceptions to this routine were Finland and Yugoslavia, each favoured by geography and supported by a powerful patriotic army. While both, in 1945, acquired left-wing, Marxist governments, both felt strong enough to resist domination by the U.S.S.R. This was not the case in Albania, Poland, Bulgaria, Romania, Hungary, and Czechoslovakia—all of which succumbed to the "pincer movement" or "salami tactics" of the Czechoslovak textbook.

In Albania there was not even a preliminary coalition. At the first postwar elections in December 1945, voters faced a single list of candidates without opposition. Not surprisingly, it won an 86 percent majority. Subsequent referenda, designed to sidestep the high rate of illiteracy, gave voters a ball to drop into a "Yes" or a "No" slot. Through the former, it fell silently into a sack; through the latter, it rattled into a can.

In Poland the postwar coalition included a minority of members returned from wartime exile in London, but a majority were their rivals, backed by the U.S.S.R., who held such key positions as the Ministry of Public Security and resorted to censorship, threats, and murder against the bourgeois parties and the press. The eventual election, held under a reign of terror in January 1947, gave a landslide victory to left-wing socialists and communists. Already in the previous September they had agreed with Stalin and Molotov on the composition of the future government.

In Bulgaria's coalition government, formed in 1944, Communists held the ministries of Interior and Justice. Purges, intimidation, and the imprisonment of opposition leaders made the eventual election a mockery. When Georgi Dimitrov (who had been one of the defendants in the German Reichstag fire trial) became prime minister of a fresh coalition in 1946, his Cabinet included nine Communist ministers, making the coalition a mere façade.

In Romania in 1945, the U.S.S.R. insisted that King Michael, who had set up a coalition government, should accept in it Communist ministers of the Interior and of Justice. In the subsequent 1946 election campaign, the Communists broke up rival meetings, persuaded printers to boycott opposition literature, and imprisoned or killed political opponents.

In Hungary the 1944 coalition included only two communist ministers, and in the 1945 election the moderate-liberal Smallholders' Party led the poll. The communists threatened to quit the government, leaving it as a minority, unless they were given the Ministry of the Interior. They organized demonstrations and insisted on the dismissal of 22 Smallholders' representatives. In December 1946 the communist ministers of Defense and of the Interior made widespread arrests. In August 1947, 35 percent of the electorate still voted for the opposition, closely linked with the Roman Catholic church. However, in 1949, after the arrest and imprisonment of József Cardinal Mindszenty, the government staged a single-list election and claimed 90 percent of the votes.

In Czechoslovakia the 1945 coalition provisional government had Communists at the ministries of the Interior, Education, Agriculture, and Information. In the 1946 election of a Constituent Assembly the Communists and their Social Democratic allies held a slender majority, and for two years the country prospered. But, as the 1948 election approached, the Communists prepared for a takeover. The minister of the Interior dismissed eight non-Communist police commanders in Prague, replacing them with party men. In the ensuing protest in the Cabinet, the non-Marxist ministers resigned, but the Social Democrats unexpectedly remained and kept the government in place. When the ex-ministers tried to return, they were ejected. The Communists, assured of backing by the U.S.S.R., staged strikes, armed workers' rallies, and a violent putsch. Their most illustrious victim was Jan Masaryk, the foreign minister, son of the republic's founder, who died on the night of March 9, 1948. Czechoslovak democracy died with him—and would not be resurrected for 40 years.

With communist ministers in the postwar governments of Belgium, France, and Italy, and with communists fomenting political strikes, some feared similar takeovers in the West. Germany, however, was the scene of the sharpest clash. For several years, by a leapfrog process of move and countermove, the eastern and western occupation zones of Germany had gradually been solidifying into separate entities. When in June 1948 the Western authorities issued a new western deutsche mark, the U.S.S.R. retaliated by imposing a land blockade on Berlin, which

The division of Germany

was jointly administered by the four occupation powers but was physically an enclave within the Soviet zone. The West responded with a massive 11-month airlift of food, goods, and raw materials. Meanwhile, 12 Western countries—Belgium, Britain, Canada, Denmark, France, Iceland, Italy, Luxembourg, The Netherlands, Norway, Portugal, and the United States—negotiated and signed on April 4, 1949, the North Atlantic Treaty, agreeing "that an armed attack against one or more of them . . . shall be considered an attack against them all." Almost immediately, the U.S.S.R. called off the Berlin blockade.

Within a few weeks, Germany was formally divided into two rival republics. The Cold War had reached a climax. Western Europe had drawn even closer to the United States.

Affluence and its underside. The West German currency reform that produced the western deutsche mark was a courageous act. It exchanged one deutsche mark for 10 obsolete reichsmarks; later the rate was slightly reduced. In one respect, the result was similar to that of Weimar's hyperinflation; paper savings were suddenly devalued. This time, however, there was a limit to any losses. What was more, quite small quantities of the new currency would actually buy goods. When Ludwig Erhard, the economic director who had undertaken the reform, also dismantled price and other controls, the scene was set for the so-called *Wirtschaftswunder,* the German "economic miracle," fueled by freedom and competition and the energy they released.

The "economic miracle"

By 1950 West Germany's gross national product had caught up with the 1936 figure. Between 1950 and 1955 the national income rose by 12 percent a year, while exports grew even faster. From a small deficit in 1950, gold and foreign currency reserves increased to nearly 13 billion deutsche marks by 1955, while unemployment fell from 2.5 million to 900,000. Per capita income nearly doubled. New homes were built at the rate of 500,000 a year. By 1955 West Germany had more than 100,000 television sets. Bombed cities had been rebuilt. Every other family seemed to possess a Volkswagen "beetle" car.

West Germany's was not the only economic miracle. France, spurred by the bright young graduates of *grandes écoles* like the Polytéchnique, was modernizing rapidly—electrifying railways, launching new power projects, discovering natural gas, building nuclear reactors, mechanizing coal mines, and designing the Caravelle jet airplane. In 1948 France's total output had been only just above the 1936 level. By 1955 it was half again as high. Between 1955 and 1958 French productivity increased by 8 percent a year, faster than anywhere else in Europe.

Italy, however, was not to be left behind. With a comparatively low starting point, plentiful labour, and new discoveries of oil and, especially, natural gas, it was able to increase the gross national product by 32.9 percent between 1950 and 1954. In Italian industry between 1950 and 1958, the average annual growth rate was 9 percent. As in West Germany, the transformation was visible: better clothes; smarter shop fronts: higher meat consumption; bicycles replaced by motor scooters and later by small cars.

In Britain, although there was no economic miracle, there were industrial success stories in chemicals, quality cars, nuclear energy, and aviation. It was a British airline that in 1952 inaugurated the world's first purely jet airline service. By the end of the decade, Heathrow in London was the busiest airport in the world.

By 1955 all western European countries were producing more than in the 1930s. Abroad, from 1952 onward, western Europe was earning more than it spent. Between 1950 and 1955, average productivity in Europe increased by 26 percent. Although British Prime Minister Harold Macmillan was both misunderstood and mocked when he made the remark, he had some justification for telling an audience on July 20, 1957: "Most of our people have never had it so good."

The benefits of middle-class affluence

The benefits, for ordinary Europeans, took many forms. There was easier access to higher education and cheaper mass travel. There was more varied food; there was better health, preserved by better medicine. There were new synthetic materials, more plentiful housing, and wider automobile ownership. There were stereophonic recordings, colour television, high-fidelity audio equipment, and cheap paperback editions of serious books. There were new, more classless eating-houses, pedestrian precincts, supermarkets, and shopping malls. What its critics called "Americanization" had arrived.

But affluence had a downside, in Europe as elsewhere. It often harmed the environment: more cars meant more roads, and more yachts meant more marinas. It multiplied the production of waste, not all of it biodegradable. It sometimes seemed to glorify greed and snobbery, especially when it passed some people by. It troubled the young and the thoughtful: their material needs sated, they might be left asking, "So what?" With money more plentiful, it was easier to be spendthrift. With greater prosperity, drug abuse and alcoholism became more common; so, paradoxically, did hooliganism and casual crime. One of the by-products of the affluent society was self-doubt and self-questioning—the kind of critique of "consumer values" that was voiced by student rebels in and around 1968. It left many Europeans unsure of their deeper objectives and, still more, of their role in a bewildering world.

The reflux of empire. One major change in the world during the decades that followed World War II was the emergence of more than 50 new sovereign states. Essentially, this was the result of decolonization.

Before World War II the countries of western Europe had ruled, controlled, or powerfully influenced vast tracts of territory overseas. The main exceptions were Spain, which had long since lost its empire, and Germany, whose colonies had been confiscated after World War I. Otherwise, Belgium, Britain, France, Italy, The Netherlands, and Portugal remained imperial powers, holding direct or indirect sway over most of Southeast Asia, parts of the West Indies, nearly all of Africa, and much of the Middle East.

Gradually, what had once been colonies, protectorates, or client states won their independence. Some 800 million people were now responsible for their own affairs. Few were richer or more secure. Many retained links with Europe—linguistic, cultural, economic or commercial; many depended on European investment and aid. But they were free of their colonial masters. Painfully, and sometimes violently, the old order had been superseded, and new relationships had to be built.

The Italian colonies in North and East Africa, like the Japanese empire in East Asia, were dismantled fairly quickly. Independence likewise came early to various Middle Eastern countries, although for many years European influence there continued. Egypt had become formally independent in 1922, Iraq in 1932, and Lebanon and Syria in 1941. Iran's independence was guaranteed by Britain and the U.S.S.R. in 1942. The year 1946 saw Jordan's independence, and 1948 the proclamation of Israel. Historical ties (including the memory of Hitler's Holocaust), strategic pressures, and the need for Middle Eastern oil kept Europe deeply involved in the area long after most of its countries' formal independence had become much more real. The Suez expedition of 1956 actually brought down a British government; oil price rises in the 1970s caused a European recession; and Saddam Hussein's invasion of Kuwait in 1990 for a time seemed to threaten the risk of world war.

British and Dutch decolonization in East Asia began in 1947 with the independence of India and the creation of Pakistan. Burma and Ceylon followed in 1948, and the Dutch East Indies in 1949. Malaya's independence was delayed until 1957 by a communist campaign of terror, quelled by both a sophisticated antiguerrilla campaign and a serious effort to win what the British General Sir Gerald Templer called "the hearts and minds of the Malayan people."

French decolonization proved more troublesome. France had given the name "Indo-China" to a million square miles in Southeast Asia, an area nearly 10 times the size of the mother country, which it had colonized in the 19th century—a union of settlements and dependencies in Tonkin, Annam, Laos, Cambodia, and Cochinchina around Saigon. As early as 1925, the Vietnam Revolu-

French troubles in Indochina and Algeria

tionary Party had been founded to fight for the unity and independence of Tonkin, Annam, and Cochinchina. In 1945 it proclaimed a democratic republic and fought the French for eight years. Following the French defeat at Dien Bien Phu in 1954, Vietnam became independent and was partitioned between Hanoi and Saigon. When communist North Vietnam began threatening and attacking the South, the United States was drawn into 10 years of unsuccessful and divisive hostilities, at a heavy cost in human life and political credibility.

France faced similar problems in North Africa. Morocco and Tunisia obtained independence in 1956, but Algeria, legally part of the French republic, aroused far fiercer passions and led to another eight-year war, from 1954 to 1962. Whereas Dien Bien Phu had brought down a French government, the Algerian War caused the downfall of the French Fourth Republic and the accession to power of de Gaulle, who had been in retirement (his second) since 1951. French settlers in Algeria cheered him when he told them: "I have understood you." Only later did they realize that his understanding embraced the need to grant Algeria independence and to crush attempted coups on the part of the settlers' right wing.

In sub-Saharan Africa, what Harold Macmillan called "the wind of change" blew less stormily. There were violent incidents and atrocities, as in the former Belgian Congo; and there were tribal and civil wars. Some white settlers hotly resisted decolonization, as in Rhodesia and South Africa. But by the 1990s only South Africa maintained white supremacy, and even there the apartheid system was being modified. Europeans were aghast at Africa's recurrent famines and concerned at the persistence of apartheid. Yet no aspect of Africa's development seemed likely to affect Europe as deeply as Indochina and Algeria had affected France.

One feature of the postcolonial period, however, was the reflux into Europe of emigrants from the former colonies. Some, civil servants and business people, had little difficulty in settling themselves. Others, with brown or black skin, faced latent racism. In Britain the first such immigrant groups, from the West Indies, were broadly welcomed. But between 1950 and 1957 Britain's immigrant population doubled, to 200,000; and the busy diligence of Indian and Pakistani shopkeepers, though welcomed by many, also aroused envy and hostility, as it had in Uganda, whence some of them had fled. In France, too, there was racial hostility, directed more often against North Africans than against black immigrants. Neither France nor Britain seemed to have studied the careful preparations that The Netherlands had made to meet similar problems with immigrants from East Asia.

In eastern Europe there was also pressure for independence from quasi-colonial rule. Signs of unrest had begun in Poland, where in June and July 1956 strikes and riots in Poznań had ended with the deaths of 53 workers. In October of that year in Hungary, there was a full-scale revolt, finally quelled on November 4 by Soviet tanks. A similar fate ended the "Prague Spring" of 1968 in Czechoslovakia. For a long time, it seemed as if eastern Europe would never be free.

Yet there too the winds of change were blowing. The accession to power of Mikhail S. Gorbachev in 1985 marked a real turning point in the U.S.S.R.: *glasnost* ("openness") replaced compulsive secrecy, and attempts at *perestroika* ("restructuring") sought to replace with efficiency the dead hand of state control. Already in Poland the workers' leader Lech Wałęsa had rallied supporters round the union banner of Solidarity; in Poland and elsewhere, as the 1980s ended, a new era began. Victims were rehabilitated; oppressive regimes were overthrown; dictators were executed; and free elections were held. For many, the most moving moment was on the night of Nov. 9–10, 1989, when the Berlin Wall was breached. Erected by the East German authorities in 1961 to prevent their citizens from fleeing to the West, the Wall was a concrete symbol of the division of Berlin, of Germany, and of Europe. Less than a year later, on Oct. 3, 1990, Germany and Berlin were both formally reunited. How long would it be before Europe was reunited too?

EVER CLOSER UNION?

Early advocates of European unity

Discussed by philosophers for centuries, actively promoted from the 1920s onward by Count Richard Coudenhove-Kalergi's Pan-European Movement, and officially proposed in 1929 by Aristide Briand on behalf of France, the idea of uniting Europe was revived again as World War II approached. In Britain a small private group that called itself Federal Union—in close touch with others at the Royal Institute of International Affairs (Chatham House)—began to campaign for unity in Europe as a last frail hope of preventing war. Some of the papers produced by its distinguished supporters, including work by Lord Lothian and Lionel Robbins, found their way to another group of activists in the Italian Resistance, led by, among others, Altiero Spinelli. One of the most stubborn of Mussolini's political prisoners, he was freed in 1943 from confinement on an island off the coast between Rome and Naples. Admiring what he called "the clean, precise thinking of the English federalists," he echoed it in the declaration he drafted for a secret grouping of Resistance leaders from eight other countries, including Germany. Britain thus contributed to Continental developments that British governments shunned for many years.

Support for European unity came from the right as well as the left, from liberals as well as *dirigistes*, from clerics as well as anticlericals, from "Atlanticists" as well as those who saw Europe as a "Third Force" between East and West. It even received official support, overt as well as implicit.

In 1939 the British Labour Party leader Clement Attlee declared: "Europe must federate or perish." In 1940, prompted by Jean Monnet, Churchill's government, in agreement with General de Gaulle, proposed a political union between Britain and France. In 1943 Churchill called for a Council of Europe after the war, and de Gaulle's colleague René Mayer suggested an economic federation. In 1944 the exiled governments of Belgium, The Netherlands, and Luxembourg signed the Benelux Convention for a future customs union. Pope Pius XII, meanwhile, had envisaged a close union of European states.

Individual supporters of European unity included not only statesmen such as Paul-Henri Spaak from Belgium, Alcide De Gasperi from Italy, Robert Schuman from France, Johan Willem Beyen from The Netherlands, Konrad Adenauer from Germany, and Joseph Bech from Luxembourg but also such well-known writers as Albert Camus, Raymond Aron, George Orwell, Denis de Rougemont, and Ignazio Silone. All urged, and many helped to organize, what Winston Churchill called in 1946 "a kind of United States of Europe."

In 1948 a number of activist organizations, coordinated by Joseph Retinger, former assistant to the late General Władysław Sikorski, head of the wartime Polish government-in-exile in London, staged a full-scale Congress of Europe in The Hague, Neth. Attended by 750 statesmen from throughout western Europe, including Spaak, De Gasperi, Churchill, Schuman, Adenauer, and a young French Resistance worker named François Mitterrand, it called for political and economic union, a European Assembly, and a European Court of Human Rights.

Some governments responded sympathetically. The postwar constitutions of France, West Germany, and Italy all envisaged limiting national sovereignty: the German text specifically looked forward to a united Europe. The British, however, were skeptical; and when in response to proposals by the French foreign minister Georges Bidault (who had attended The Hague Congress) the governments took action, it was of limited scope. In May 1949 they set up the Council of Europe, consisting of a Committee of Ministers and a Consultative Assembly.

The Council of Europe

To the activists, it was something; but it was not enough. The Council of Europe's main achievement, apart from useful studies and discussions, was to produce the European Convention for the Protection of Human Rights (1950), effectively backed by a court and a commission. But the Consultative Assembly was just that: it had no power, and the Committee of Ministers had a veto.

The initiative to go further came from Monnet. His opportunity came when France was at loggerheads with

Britain and the United States, both of which sought to remove the postwar restraints preventing German heavy industry from making its full contribution to the prosperity of the West. Monnet proposed to sidestep the dilemma by pooling coal and steel production in western Europe, including West Germany's, under common institutions to replace with a light and shared rein the heavy control that the International Ruhr Authority had imposed on West Germany alone.

This was the essence of what became the Schuman Plan in 1950 when Robert Schuman, by then the French foreign minister, accepted it after Georges Bidault, the prime minister, had neglected to take it up. Its end product, initially embracing only six nations, was the formation of the European Coal and Steel Community, which began work in 1952.

Monnet and Schuman saw this as only a first step on the way to a European federation. Monnet followed it by proposing to René Pleven a similar solution to the problem of German rearmament: a European Defense Community. When that eventually failed, he proposed to Spaak and Beyen what became in 1958 the European Economic Community (EEC) and the European Atomic Energy Community (Euratom), a similar organization for the peaceful use of nuclear energy. The three institutions were ultimately merged to become the European Communities (EC) in 1967. With a Council of Ministers to make essential decisions (if need be by majority vote), a Commission to propose policy, and a European Parliament and Court of Justice to exert, respectively, legislative and judicial control, the EC had the embryo of a federal constitution, limited to economic and social affairs.

The European Communities

It also had the potential for crises, growth, and enlargement. Its first major crisis, indeed, concerned enlargement, when President de Gaulle vetoed the first British application to join, in 1963. The second crisis, two years later, was also provoked by de Gaulle, who objected to the extension of majority voting.

The EC weathered both crises and proceeded to recruit new members alongside the original six of France, West Germany, Italy, and the three Benelux countries. First came Britain, Ireland, and Denmark, followed by Greece, Spain, and Portugal—with further candidates in the offing, notably Austria, Turkey, and Sweden. The possibility of further extension in eastern Europe was also mooted, despite doubts whether eastern European countries could yet face full EC competition and whether the EC might not be slowed down by too many new recruits.

The EC has developed. Its basic customs union was to be completed by the removal of all nontariff barriers in a "single market" by the end of 1992. It has formed association agreements with the members of the European Free Trade Association (Austria, Norway, Sweden, Switzerland, Liechtenstein, Finland, and Iceland), set up alongside the EC by those European countries that failed to join. It has contracted aid and trade arrangements throughout the world, notably with African, Caribbean, and Pacific countries, many of them former colonies of its member states. In trade negotiations, it is big enough to act as an equal partner to the United States. It seeks economic and monetary union, with the possibility of ultimately adopting a single currency. It has set in place machinery for foreign policy coordination called "European Political Co-operation." It is pledged by treaty to "ever closer union." Only future generations can decide how close that may become.

The EC was founded in response to a checkered half-century of European history. In 50 years some of the world's most civilized nations had plumbed depths of savagery, folly, tyranny, and genocide that in a work of science fiction would be hard to believe. The time had surely come to learn lessons from the past.

Aims of the European Communities

The EC's first and most obvious purpose was to reconcile former enemies and prevent war. This meant not only forging indissoluble bonds between France and Germany but bringing Germany into the Western fold as an equal and not as an inferior, the victim of Versailles-style reprisals. By cementing Western unity, moreover, unilateral national action could be made impossible, eliminating the fear of revanche toward the East. The EC could thus be seen as an element in "confidence building" between East and West.

Its second aim was to avoid the economic errors that Europeans had made in the 1930s, when instead of a global recovery policy they had worsened the crisis by the beggar-my-neighbour tactic of every man for himself. Economic nationalism of that sort had been the breeding ground for dictatorship. After World War II the foundations of a better approach had been laid by the OEEC. The EC went further, by pooling economic resources in a "common market," making national protectionist measures ever more difficult, and appointing an independent commission responsible for seeing the EC's problems not from separate national viewpoints but collectively, as a whole.

Meanwhile, Europe's world status had drastically changed. Its individual nations, once great powers, were dwarfed—politically and militarily by the United States and the Soviet Union (until its dissolution in 1991–92), numerically by them and by India and China, economically by the United States, Japan, and any new economic powers that might emerge. Europe's empires had been dismantled; and yet, like the rest of the world's rich Northern Hemisphere, it could not shrug off the poor and hungry millions in the South. All the more reason, therefore, for European countries to come together—not merely to hold their own vis-à-vis political and economic superpowers but also to maximize their power to meet their wider responsibilities in the world.

Finally, 20th-century Europe had witnessed and shared in extraordinarily rapid technological change. Computers, industrial robots, and genetic engineering are only its most obvious recent examples. The splitting of the atom had vastly multiplied humanity's power to destroy itself. Jet aircraft, space travel, and electronic telecommunications had revolutionized the sense of distance and scale. Radio and television, still more than the cinema, had become truly "mass media," with satellites giving all broadcasts global range.

But economic progress had not kept pace with technology; in a world of potential plenty and well-being, there were still both penury and pollution. Political progress had been slower still. International cooperation was increasing, but the basic political unit remained the nation-state. That dated from an age when the fastest means of travel had been a galloping horse. This was why the founders of the EC, as Monnet said, were not concerned to make coalitions of states but to unite people. A united Europe along these lines, with common rules and democratic institutions, was in his eyes a pilot plant for a united world. (R.J.Ma.)

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H.H. SCULLARD, *A History of the Roman World: 753–146 BC*, 4th ed. (1980), is a standard comprehensive survey. Other relevant histories are JACQUES HEURGON, *The Rise of Rome to 264 B.C.* (1973; originally published in French, 1969); KURT A. RAAFLAUB (ed.), *Social Struggles in Archaic Rome: New Perspectives on the Conflict of the Orders* (1986), focusing on the social life, customs, and class structure of republican Rome; WILLIAM V. HARRIS, *War and Imperialism in Republican Rome, 327–70 B.C.* (1979, reprinted 1985), on Roman expansion; JOSEPH VOGT, *The Decline of Rome: The Metamorphosis of Ancient Civilization* (1967; originally published in German, 1965); and A.H.M. JONES, *The Later Roman Empire, 284–602: A Social Economic and Administrative Survey*, 2 vol. (1964, reprinted 1986). MICHAEL GRANT and RACHEL KITZINGER (eds.), *Civilization of the Ancient Mediterranean: Greece and Rome*, 3 vol. (1988), is a comprehensive collection of essays on cultural, economic, and social life in the classical world.

Brief illustrated surveys of 600 years of postclassical history are presented in GERALD SIMONS, *Barbarian Europe* (1968); and PHILIP DIXON, *Barbarian Europe* (1976). OTTO J. MAENCHEN-HELFEN, *The World of the Huns: Studies in Their History and Culture* (1973), offers a scholarly examination of the development of early Europe. (Ed.)

The Middle Ages. A broad picture of the transition from the classical world to the Middle Ages is presented in PETER BROWN, *The World of Late Antiquity, AD 150–750* (1971, reissued 1989); TIM CORNELL and JOHN MATTHEWS, *Atlas of the Roman World* (1982); J.M. WALLACE-HADRILL, *The Barbarian West 400–1000*, 3rd rev. ed. (1967, reprinted 1988); JAMES CAMPBELL, ERIC JOHN, and PATRICK WORMALD, *The Anglo-Saxons* (1982); MICHAEL COOK, *Muhammad* (1983); and RICHARD HODGES and DAVID WHITEHOUSE, *Mohammed, Charlemagne, & the Origins of Europe: Archaeology and the Pirenne Thesis* (1983). The Christianization of Europe is explored in JUDITH HERRIN, *The Formation of Christendom* (1987); and JEFFREY RICHARDS, *The Popes and the Papacy in the Early Middle Ages, 476–752* (1979). Historical dynamics across several centuries are analyzed in such national surveys as ROGER COLLINS, *Early Medieval Spain: Unity in Diversity, 400–1000* (1983); EDWARD JAMES, *The Origins of France: From Clovis to Capetians, 500–1000* (1982); and CHRIS WICKHAM, *Early Medieval Italy: Central Power and Local Society, 400–1000* (1981). For relevant topical studies, see P.H. SAWYER and I.N. WOOD, *Early Medieval Kingship* (1977); PIERRE RICHÉ, *Education and Culture in the Barbarian West, Sixth Through Eighth Centuries* (1976; originally published in French, 1973); and GEORGES DUBY, *The Early Growth of the European Economy: Warriors and Peasants from the Seventh to the Twelfth Century* (1974; originally published in French, 1973).

The fullest account in English of medieval Europe is found in the appropriate volumes of the multivolume series *Cambridge Medieval History* (1911–), a new edition of which is an ongoing publication. Accessible later introductions include, in a series, CHRISTOPHER BROOKE, *Europe in the Central Middle Ages, 962–1154*, 2nd ed. (1987); JOHN H. MUNDY, *Europe in the High Middle Ages, 1150–1309* (1973); DENYS HAY, *Europe in the Fourteenth and Fifteenth Centuries*, 2nd ed. (1989); and DANIEL WALEY, *Later Medieval Europe: From Saint Louis to Luther*, 2nd ed. (1985). H.G. KOENIGSBERGER, *Medieval Europe, 400–1500* (1987), is a concise comprehensive survey. JACQUES LE GOFF, *Time, Work, & Culture in the Middle Ages* (1980; originally published in French, 1977), provides an introduction to social history. Development of agrarian society and the economy are examined in GEORGES DUBY, *Rural Economy and Country Life in the Medieval West* (1968, reprinted 1990; originally published in French, 1962); and ROBERT H. BAUTIER, *The Economic Development of Medieval Europe*, trans. from French (1971). FRANÇOIS L. GANSHOF, *Feudalism*, 2nd ed. (1961; originally published in French, 1947), analyzes the structure of feudal society; see also GEORGES DUBY, *The Chivalrous Society*, trans. from French (1977), on social classes. FRITZ KERN, *Kingship and Law in the Middle Ages* (1939, reprinted 1985; originally published in German, 1914), remains the most accessible introduction to the subject of monarchy, law, and constitutional history.

The most detailed accounts of the medieval church are the appropriate volumes of the multivolume *Handbook of Church History*, ed. by HUBERT JEDIN and JOHN DOLAN, 10 vol. (1965–1981; originally published in German, 3rd German ed., 1962–1979). Further treatments are offered in BERNARD HAMILTON, *Religion in the Medieval West* (1986); R.W. SOUTHERN, *Western Society and the Church in the Middle Ages* (1970, reprinted 1985); FRANCIS OAKLEY, *The Western Church in the Later Middle Ages* (1979, reprinted 1985); J.M. WALLACE-HADRILL, *The Frankish Church* (1983); and COLIN MORRIS, *The Papal Monarchy: The Western Church from 1050 to 1250* (1989). Intellectual life is explored in MICHAEL HAREN, *Medieval Thought: The Western Intellectual Tradition from Antiquity to the Thirteenth Century* (1985); and J.H. BURNS (ed.), *The Cambridge History of Medieval Political Thought c. 350–c. 1450* (1988). Urban cultures are the subject of HENRI PIRENNE, *Medieval Cities: Their Origins and the Revival of Trade*, trans. from French (1925, reissued 1956), retaining much of its historical value; DANIEL WALEY, *The Italian City-Republics*, 3rd ed. (1988); and JACQUES HEERS, *Parties and Political Life in the Medieval West*, trans. from French (1977), offering further detail. J. HUIZINGA, *The Waning of the Middle Ages: A Study of the Forms of Life, Thought, and Art in France and the Netherlands in the XIVth and XVth Centuries* (1924, reprinted 1985; originally published in Dutch, 1919), is a brilliant and widely influential interpretation of decline and decadence, but it provides a controversial point of view of the rich and varied culture of the Northern countries. (J.E.He./Ma.Br.)

The Renaissance. *Historiographical problems:* JACOB BURCKHARDT, *The Civilization of the Renaissance in Italy* (1890; originally published in German, 1860), is a classic work, elegant and stimulating, available in many later editions, but its thesis, that 14th-century Italians broke abruptly with their medieval past to create modern states and a highly individualistic secular society and culture, has been heavily modified by most modern specialists. WALLACE K. FERGUSON, *The Renaissance in Historical Thought: Five Centuries of Interpretation* (1948, reprinted 1981), offers an excellent introduction, but recent scholarship has expanded the range and depth of knowledge and dissolved such interpretive consensus as still existed when Ferguson wrote. E.F. JACOB (ed.), *Italian Renaissance Studies* (1960); HAWLEY HELTON (ed.), *The Renaissance: A Reconsideration of the Theories and Interpretations of the Age* (1961, reprinted 1980); and DENYS HAY, *The Italian Renaissance in Its Historical Background*, 2nd ed. (1977), characterize the interpretations of the 1960s. At present most Renaissance historians

do not make the sweeping characterizations of the "spirit of an age" that once came so easily. An excellent historiographical and bibliographical guide to works about Europe outside Italy is STEVEN OZMENT (ed.), *Reformation Europe: A Guide to Research* (1982), not really limited to the Reformation.

The Italian Renaissance: LAURO MARTINES, *Power and Imagination: City-States in Renaissance Italy* (1979, reissued 1988), provides an informative survey. Florentine history is authoritatively surveyed in GENE BRUCKER, *Renaissance Florence* (1969, reissued 1983). ERIC COCHRANE, *Florence in the Forgotten Centuries, 1527–1800: A History of Florence and the Florentines in the Age of the Grand Dukes* (1973), ventures beyond the fall of the Florentine republic. Venetian history is ably treated in D.S. CHAMBERS, *The Imperial Age of Venice, 1380–1580* (1970); WILLIAM H. MCNEILL, *Venice: The Hinge of Europe, 1081–1797* (1974, reprinted 1986); and ROBERT FINLAY, *Politics in Renaissance Venice* (1980). Social and cultural conditions and religious life are approached in BRIAN PULLAN, *Rich and Poor in Renaissance Venice: The Social Institutions of a Catholic State, to 1620* (1971); RICHARD C. TREXLER, *Public Life in Renaissance Florence* (1980); DAVID HERLIHY and CHRISTIANE KLAPISCH-ZUBER, *Tuscans and Their Families: A Study of the Florentine Catasto of 1427* (1985; originally published in French, 1978); RONALD F.E. WEISSMAN, *Ritual Brotherhood in the Renaissance Florence* (1982); EDWARD MUIR, *Civic Ritual in Renaissance Venice* (1981); and DONALD E. QUELLER, *The Venetian Patriciate: Reality Versus Myth* (1986). JOAN KELLY, "Did Women Have a Renaissance?" in her *Women, History, & Theory* (1984), challenged Burckhardt's thesis that women achieved equality with men in Renaissance Italy. See also IAN MACLEAN, *The Renaissance Notion of Woman: A Study in the Fortunes of Scholasticism and Medical Science in European Intellectual Life* (1980); CHRISTIANE KLAPISCH-ZUBER, *Women, Family, and Ritual in Renaissance Italy*, trans. from French (1985); and MARGARET W. FERGUSON, MAUREEN QUILLIGAN, and NANCY J. VICKERS (eds.), *Rewriting the Renaissance: The Discourses of Sexual Difference in Early Modern Europe* (1986). SAMUEL KLINE COHN, JR., *The Laboring Classes in Renaissance Florence* (1980), is a controversial ground-breaking study.

A good starting point for the study of Renaissance intellectual history is PAUL OSKAR KRISTELLER, *Renaissance Thought: The Classic, Scholastic, and Humanistic Strains*, rev. ed. (1961), and *Renaissance Thought II: Papers on Humanism and the Arts* (1965, reissued 1980). EUGENIO GARIN, *Italian Humanism: Philosophy and Civic Life in the Renaissance*, trans. from Italian (1965, reprinted 1975); and HANS BARON, *The Crisis of the Early Italian Renaissance: Civic Humanism and Republican Liberty in an Age of Classicism and Tyranny*, rev. ed. (1966), treat humanism as a civic ethos as well as a scholarly and educational movement; while CHARLES TRINKAUS, *In Our Image and Likeness: Humanity and Divinity in Italian Humanist Thought*, 2 vol. (1970), disproves the notion of humanism as primarily secular. ERNEST H. WILKINS, *Life of Petrarch* (1961), provides information on the acknowledged founder of Renaissance humanism. RONALD G. WITT, *Hercules at the Crossroads: The Life, Works, and Thought of Coluccio Salutati* (1983), is an excellent study of a figure second only to Petrarch in importance. GEORGE HOLMES, *Florence, Rome, and the Origins of the Renaissance* (1986), revives an old thesis attributing the origins of the Renaissance to the age of Dante. Studies of humanist culture outside Florence include J.K. HYDE, *Padua in the Age of Dante* (1966); JOHN F. D'AMICO, *Renaissance Humanism in Papal Rome: Humanists and Churchmen on the Eve of the Reformation* (1983); CHARLES L. STINGER, *The Renaissance in Rome* (1985); JERRY H. BENTLEY, *Politics and Culture in Renaissance Naples* (1987); and MARGARET L. KING, *Venetian Humanism in an Age of Patrician Dominance* (1986). A lively revisionist view that challenges basic assumptions about the history of Renaissance humanism is presented in ANTHONY GRAFTON and LISA JARDINE, *From Humanism to the Humanities: Education and the Liberal Arts in Fifteenth- and Sixteenth-Century Europe* (1986). On the current state of studies on humanism, see ALBERT RABIL, JR. (ed.), *Renaissance Humanism: Foundations, Forms, and Legacy*, 3 vol. (1988).

The classic account of the development of diplomacy is GARRETT MATTINGLY, *Renaissance Diplomacy* (1955, reprinted 1988); see also JOYCELYNE G. RUSSELL, *Peacemaking in the Renaissance* (1986). On warfare, see MICHAEL MALLETT, *Mercenaries and Their Masters: Warfare in Renaissance Italy* (1974), FELIX GILBERT, *Machiavelli and Guicciardini: Politics and History in Sixteenth-Century Florence* (1965, reprinted 1984), provides the political and cultural context of the thought of two leading Renaissance political scholars. J.G.A. POCOCK, *The Machiavellian Moment: Florentine Political Thought and the Atlantic Republican Tradition* (1975), traces the Renaissance heritage to modern times. SEBASTIAN DE GRAZIA, *Machiavelli in Hell* (1989), is a fresh, lively intellectual biography of the great Florentine.

Science and technology: ELIZABETH L. EISENSTEIN, *The Printing Press as an Agent of Change: Communications and Cultural Transformations in Early Modern Europe*, 2 vol. (1979), and *The Printing Revolution in Early Modern Europe* (1983), make a strong case for the revolutionary impact of Renaissance print technology upon culture. The concept of a "scientific revolution" is upheld in such standard works as HERBERT BUTTERFIELD, *The Origins of Modern Science: 1300–1800*, rev. ed. (1957, reprinted 1982); I. BERNARD COHEN, *From Leonardo to Lavoisier, 1450–1800* (1980); and A. RUPERT HALL, *The Revolution in Science, 1500–1750*, 3rd ed. (1983); while the continuities with medieval science are stressed in A.C. CROMBIE, *Medieval and Early Modern Science*, 2nd rev. ed. (1959, reissued 1967). Feminist theorists have made some influential contributions to revisionist perspectives deploring the "triumphalism" with which scientific advance has been treated: see, for example, EVELYN FOX KELLER, *Reflections on Gender and Science* (1985).

The Renaissance outside Italy: New areas of investigation in social history, including the history of the lower classes, women, the family, and popular religion, are exemplified in EMMANUEL LE ROY LADURIE, *The Peasants of Languedoc* (1974; originally published in French, 1966); PETER LASLETT, *The World We Have Lost: Further Explored*, 3rd. ed. (1984); NATALIE ZEMON DAVIS, *Society and Culture in Early Modern France* (1975, reissued 1987); PETER BURKE, *Popular Culture in Early Modern Europe* (1978, reprinted 1988); RICHARD KIECKHEFER, *European Witch Trials: Their Foundations in Popular and Learned Culture, 1300–1500* (1976); STEVEN OZMENT, *When Fathers Ruled: Family Life in Reformation Europe* (1983); JOSEPH KLAITS, *Servants of Satan: The Age of the Witch Hunts* (1985); and BRIAN P. LEVACK, *The Witch-Hunt in Early Modern Europe* (1987).

In religious history there has been a tendency to reconstruct the bridges between the late medieval and Reformation piety and thought. One of the most influential examples of this effort is HEIKO AUGUSTINUS OBERMAN, *The Harvest of Medieval Theology: Gabriel Biel and Late Medieval Nominalism* (1963, reissued 1983), and HEIKO AUGUSTINUS OBERMAN (ed.), *Forerunners of the Reformation: The Shape of Late Medieval Thought* (1966, reissued 1981). Other important studies include STEVEN E. OZMENT (ed.), *The Reformation in Medieval Perspective* (1971); and THOMAS N. TENTLER, *Sin and Confession on the Eve of the Reformation* (1977). Another, not necessarily contradictory, tendency has been that of seeing the history of late medieval and Renaissance religion in its own terms, rather than as the prelude to the Reformation: see CHARLES TRINKAUS and HEIKO AUGUSTINUS OBERMAN (eds.), *The Pursuit of Holiness in Late Medieval and Renaissance Religion* (1974); and RICHARD KIECKHEFER, *Unquiet Souls: Fourteenth-Century Saints and Their Religious Milieu* (1984). An original and valuable, if sometimes debatable, overview is JOHN BOSSY, *Christianity in the West, 1400–1700* (1985).

The emergence of modern Europe. The economic backgound is discussed in a variety of studies. CARLO M. CIPOLLA, *Before the Industrial Revolution: European Society and Economy, 1000–1700*, 2nd ed. (1980; originally published in Italian, 1974), offers a treatment of the economy focusing not so much on history as on social structures. IMMANUEL WALLERSTEIN, *The Modern World-System*, 3 vol. (1974–89), covers the period from the 16th to the mid-19th century, emphasizing spatial division of the early capitalistic world among core areas, semiperipheries, and peripheries. Another broad, rich, and learned reconstruction of the world of early capitalism is offered in FERNAND BRAUDEL, *Civilization and Capitalism, 15th–18th Century*, 3 vol. (1982–84; originally published in French, 1979).

Comprehensive works include RONDO CAMERON, *A Concise Economic History of the World: From Paleolithic Times to the Present* (1989); HARRY A. MISKIMIN, *The Economy of Later Renaissance Europe, 1460–1600* (1977), stressing concepts of law as a critical factor in economic development; E.E. RICH and C.H. WILSON (eds.), *The Economy of Expanding Europe in the Sixteenth and Seventeenth Centuries* (1967); JAN DE VRIES, *Economy of Europe in an Age of Crisis, 1600–1750* (1976), exploring the 17th-century unraveling of the 16th-century world, and *European Urbanization, 1500–1800* (1984), a broader survey; WITOLD KULA, *An Economic Theory of the Feudal System: Towards a Model of the Polish Economy, 1500–1800*, new ed. (1976, reissued 1987; originally published in Polish, 1962), an analysis of a particular 16th-century economy; and PIERO CAMPORESI, *Bread of Dreams: Food and Fantasy in Early Modern Europe* (1989; originally published in Italian, 1980), an exploration of malnutrition with an impressive picture of some unpalatable food and the symbolism of its consumption.

For demographics, see JOSIAH COX RUSSELL, *The Control of Late Ancient and Medieval Population* (1985), a historical study of European communities; and E.A. WRIGLEY and R.S. SCHOFIELD, *The Population History of England, 1541–1871: A Reconstruction* (1981), utilizing new techniques of reconstruction and backward projection of census data.

Studies of protoindustrialization include PETER KRIEDTE *et al., Industrialization Before Industrialization: Rural Industry in the Genesis of Capitalism* (1981; originally published in German, 1977), in a German context; JOHN U. NEF, *Industry and Government in France and England, 1540–1640* (1940, reprinted 1968), still informative and focusing on the interaction of power; and PAUL SWEEZY *et al., The Transition from Feudalism to Capitalism* (1976), a collection of Marxist debate as to what capitalism really was and when it began.

On finance, see EARL J. HAMILTON, *American Treasure and the Price Revolution in Spain, 1501–1650* (1934, reprinted 1977), a classic that launched a continuing debate. Political and cultural influences are the subject of PERRY ANDERSON, *Lineages of the Absolutist State* (1974), a Marxist view of the role of the state in the birth of modern capitalism; SIMON SCHAMA, *The Embarrassment of Riches: An Interpretation of Dutch Culture in the Golden Age* (1987), a lengthy and entertaining exploration; KEITH THOMAS, *Religion and the Decline of Magic* (1971), on the impact of the culture of Reformation; and R.H. TAWNEY, *Religion and the Rise of Capitalism* (1926, reissued 1984), a classic study of Calvinism and the capitalistic ethos.

A broader approach to early modern society is offered, summarily, in PETER BURKE, *The Historical Anthropology of Early Modern Italy: Essays on Perception and Communication* (1987), focusing on detail rather than central movements of early modern culture; ROGER CHARTIER (ed.), *Passions of the Renaissance* (1989; originally published in French, 1986), a volume of essays dealing with the period from the Renaissance to Enlightenment, from the series *A History of Private Life*; BRIAN PULLAN, *The Jews of Europe and the Inquisition of Venice, 1550–1670* (1983), an often poignant examination of ethnic relations; and CARLO GINZBURG, *The Cheese and the Worms: The Cosmos of a Sixteenth-Century Miller* (1980; originally published in Italian, 1976), an excellent social history based on the story of an eccentric miller and his cosmological views.

Politics and diplomacy are dealt with in many general histories of the period. Narrative and analytical accounts, with detailed bibliographies, are offered in J.R. HALE, *Renaissance Europe, 1480–1520* (1971, reprinted 1985), G.R. ELTON, *Reformation Europe, 1517–1559* (1963); J.H. ELLIOTT, *Europe Divided, 1559–1598* (1968, reprinted 1985); and GEOFFREY PARKER, *Europe in Crisis, 1598–1648* (1979), all four in the *Fontana History of Europe* series. G.R. POTTER (ed.), *The Renaissance, 1493–1520* (1957); G.R. ELTON (ed.), *The Reformation, 1520–1559*, 2nd ed. (1990); R.B. WERNHAM (ed.), *The Counter-Reformation and Price Revolution, 1559–1610* (1968); and J.P. COOPER (ed.), *The Decline of Spain and the Thirty Years War, 1609–48/59* (1970), the first four volumes in *The New Cambridge Modern History* series, offer a sequence of chapters by various authors, thematically organized. H.G. KOENIGSBERGER, GEORGE L. MOSSE, and G.Q. BOWLER, *Europe in the Sixteenth Century*, 2nd ed. (1989), treats the earlier part of the period. The last 50 years of the period, dominated by the genesis and course of continental war, are best approached through GEOFFREY PARKER (ed.), *The Thirty Years' War*, rev. ed. (1987). (D.He./N.G.P.)

The age of absolutism, 1648–1789. GORDON EAST, *An Historical Geography of Europe*, 5th ed. (1966), provides an informative introduction to geographic features influencing the history of the period. For definition, see H.D. SCHMIDT, "The Establishment of 'Europe' as a Political Expression," *The Historical Journal* 9(2):172–178 (1966). Main themes are covered in the essays of G.N. CLARK, *The Seventeenth Century*, 2nd ed. (1947, reprinted 1981); and the appropriate volumes of *The New Cambridge Modern History* series (1957–). General surveys include E.N. WILLIAMS, *The Ancien Régime in Europe: Government and Society in the Major States, 1648–1789* (1970); D.H. PENNINGTON, *Seventeenth-Century Europe* (1970); GEOFFREY TREASURE, *The Making of Modern Europe, 1648–1780* (1985); M.S. ANDERSON, *Europe in the Eighteenth Century, 1713–1783*, 3rd ed. (1987); and WILLIAM DOYLE, *The Old European Order, 1660–1800* (1978, reprinted 1984). Specific social and demographic questions are explored in EMMANUEL LE ROY LADURIE, *Times of Feast, Times of Famine: A History of Climate Since the Year 1000* (1971, reissued 1988; originally published in French, 1967); MICHAEL W. FLINN, *The European Demographic System, 1500–1820* (1981); LUCIEN LEFEBVRE, *A New Kind of History: From the Writings of Febvre*, trans. from French, ed. by PETER BURKE (1973); ROBERT MANDROU, *Introduction to Modern France, 1500–1640: An Essay in Historical Psychology* (1975; originally published in French, 1961); PHILIPPE ARIÈS, *Centuries of Childhood: A Social History of Family Life* (1962, reissued 1979; originally published in French, 1960); JOHN MCMANNERS, *Death and the Enlightenment: Changing Attitudes to Death Among Christians and Unbelievers in Eighteenth-Century France* (1981); and KEITH THOMAS, *Man and the Natural World: A History of the Modern Sensibility* (1983, also published as *Man and the Natural World: Changing Attitudes in England, 1500–1800*, 1983). See also OLWEN H. HUFTON, *The Poor of Eighteenth-Century France, 1750–1789* (1974), for a study of poverty, with much about women; MICHAEL R. WEISSER, *Crime and Punishment in Early Modern Europe* (1979); and E.J. HOBSBAWM, *Bandits*, rev. ed. (1981).

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The History of European Overseas Exploration and Empires

The motives that spur human beings to examine their environment are many. Strong among them are the satisfaction of curiosity, the pursuit of trade, the spread of religion, and the desire for security and political power. At different times and in different places, different motives are dominant. Sometimes one motive inspires the promoters of discovery, and another motive may inspire the individuals who carry out the search. Still other motives draw settlers to the new territory.

Since the settlement of the European continent, its people have shown an inclination to explore and expand from their geographic centre. Exploration of the Mediterranean world led to contacts with northern and western Europeans that extended the knowledge and culture of both groups. The impetus toward expansion, demonstrated in the establishment of the Hellenistic and Roman empires, continued as Christianity spread through Europe and beyond. Colonization of conquered territories was undertaken, especially by the Romans, but on a much smaller scale than that which followed in the early modern world. The major benefit of early, indeed of all, European expansion was the cultural enrichment that resulted from contact with other civilizations. (J.B.Mi./Ed.)

The major period of European colonization had its origin with the Renaissance, the development of modern science, and the great voyages of discovery. This period began about 1500 and reached its peak in the early 1900s, when the last independent territories of Asia and Africa were parcelled out. Following World War II the strengthening of nationalistic movements opposed to colonialism and the erosion of dominance caused by the modernization of economic systems brought about the decline of the colonial empires.

For a discussion of the society that engaged in these explorations, and their effects on intra-European affairs, see EUROPEAN HISTORY AND CULTURE. The earliest European empires are discussed in GREEK AND ROMAN CIVILIZATIONS, ANCIENT.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 961, and the *Index*. This article is divided into the following sections:

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EUROPEAN EXPLORATION

The threads of geographical exploration are continuous and, being entwined one with another, are difficult to separate; three major phases of investigation may nevertheless be distinguished. The first phase is the exploration of the Old World centred on the Mediterranean Sea; the second is the so-called Age of Discovery, during which, in the search for sea routes to Cathay (the name by which China was known to medieval Europe), a New World was found; the third is the establishment of the political, social, and commercial relationships of the New World to the Old and the elucidation of the major physical features of the continental interiors—in short, the delineation of the modern world.

The exploration of the Old World

From the time of the earliest recorded history to the beginning of the 15th century, Western knowledge of the world widened from a river valley surrounded by mountains or desert (the views of Babylonia and Egypt) to a Mediterranean world with hinterlands extending from the Sahara to the Gobi deserts and from the Atlantic to the Indian oceans (the view of Greece and Rome). It later expanded again to include the far northern lands beyond the Baltic and another and dazzling civilization in the Far East (the medieval view).

The earliest known surviving map, dating probably from



Map showing the geographical knowledge of the world derived from the writings of Hecataeus of Miletus, *c.* 500 BC.
By courtesy of the Library of Congress, Washington, D.C.

The earliest known map

the time of Sargon of Akkad (about 2334–2279 BC), shows canals or rivers—perhaps the Tigris and a tributary—and surrounding mountains. The rapid colonization of the shores of the Mediterranean and of the Black Sea by Phoenicia and the Greek city-states in the first millennium BC must have been accompanied by the exploration of their hinterlands by countless unknown soliders and traders. Herodotus prefaces his *History* (written in the 5th century BC) with a geographical description of the then known world: this introductory material reveals that the coastlines of the Mediterranean and the Black Sea had by then been explored.

Stories survive of a few men who are credited with bringing new knowledge from distant journeys. Herodotus tells of five young adventurers of the tribe of the Nasamones living on the desert edge of Cyrenaica in North Africa, who journeyed southwest for many months across the desert, reaching a great river flowing from west to east; this presumably was the Niger, although Herodotus thought it to be the Upper Nile.

EXPLORATION OF THE ATLANTIC COASTLINES

Beyond the Pillars of Hercules (the Strait of Gibraltar), the Carthaginians (from the Phoenician city of Carthage in what is now Tunisia), holding both shores of the strait, early ventured out into the Atlantic. A Greek translation of a Punic (Carthaginian) inscription states that Hanno, a Carthaginian, was sent forth about 500 BC with 60 ships and 30,000 colonists "to found cities." Even allowing for a possible great exaggeration of numbers, this expedition, if it occurred, can hardly have been the first exploratory voyage along the coast of West Africa; indeed, Herodotus reports that Phoenicians circumnavigated the continent about 600 BC. Some scholars think that Hanno reached only the desert edge south of the Atlas; other scholars identify the "deep river infested with crocodiles and hippopotamuses" with the Sénégal River; and still others believe that the island where men "scampered up steep rocks and pelted us with stones" was an island off the coast of Sierra Leone. There is no record that Hanno's voyage was followed up before the era of Henry the Navigator, a Portuguese prince of the 15th century.

About the same time, Himilco, another Carthaginian, set forth on a voyage northward; he explored the coast of Spain, reached Brittany, and in his four-month cruise may have visited Britain. Two centuries later, about 300 BC, Carthaginian power at the gate of the Mediterranean temporarily slackened as a result of squabbles with the Greek city of Syracuse on the island of Sicily, so Pytheas, a Greek explorer of Massilia (Marseille), sailed through. His story is known only from fragments of the work of a contemporary historian, Timaeus (who lived in the 4th and 3rd centuries BC), as retold by the Roman savant Pliny the Elder, the Greek geographer Strabo, and the Greek historian Diodorus Siculus, all of whom were critical of its truth. It is probable that Pytheas, having coasted the shores of the Bay of Biscay, crossed from the island of Ouessant (Ushant), off the French coast of Brittany, to Cornwall in southwestern England, perhaps seeking tin. He may have sailed around Britain; he describes it as a triangle and also relates that the inhabitants "harvest grain crops by cutting off the ears . . . and storing them in covered granges." Around Thule, "the northernmost of the British Isles, six days sail from Britain," there is "neither sea nor air but a mixture like sea-lung . . . binds everything together," a reference perhaps to drift ice or dense sea fog. Thule has been identified with Iceland (too far north), with Mainland island of the Shetland group (too far south), and perhaps, most plausibly, with Norway. Pytheas returned to Brittany and explored "beyond the Rhine"; he may have reached the Elbe. The voyage of Pytheas, like that of Hanno, does not seem to have been followed up. Herodotus concludes by saying, "whether the sea girds Europe round on the north none can tell."

The Northmen

It was not Mediterranean folk but Northmen from Scandinavia, emigrating from their difficult lands centuries later, who carried exploration farther in the North Atlantic. From the 8th to the 11th century bands of Northmen, mainly Swedish, trading southeastward across the Russian plains, were active under the name of Varangians in the ports of the Black Sea. At the same time other groups, mainly Danish, raiding, trading, and settling along the coasts of the North Sea, arrived in the Mediterranean in the guise of Normans. Neither the Swedes nor the Danes travelling in these regions were exploring lands that were unknown to civilized Europeans, but it is doubtless that contact with them brought to these Europeans new knowledge of the distant northern lands.

It was the Norsemen of Norway who were the true explorers though, since little of their exploits was known to contemporaries and that little soon forgotten, they perhaps added less to the common store of Europe's knowledge than their less adventurous compatriots. About AD 890, Ohthere of Norway, "desirous to try how far that country extended north," sailed round the North Cape, along the coast of Lapland to the White Sea. But most Norsemen sailing in high latitudes explored not eastward but westward. Sweeping down the outer edge of Britain, settling in Orkney, Shetland, the Hebrides, and Ireland, they then voyaged on to Iceland, where in 870 they settled among Irish colonists who had preceded them by some two centuries. The Norsemen may well have arrived piloted by Irish sailors; and Irish refugees from Iceland, fleeing before the Norsemen, may have been the first discoverers of Greenland and Newfoundland, although this is mere surmise. The saga of Erik the Red (*Eiriks saga rauda*; also called *Thorfinns saga Karlsefnis*), gives the story of the Norse discovery of Greenland in 982; the west coast was explored, and at least two settlements were established on it. About AD 1000, one Bjarni Herjulfsson, on his way from Iceland to Greenland, was blown off course far to the southwest; he saw an unknown shore and returned to tell his tale. Leif, Erik's son, together with some 30 others, set out in 1001 to explore. They probably reached the coasts of Labrador and Newfoundland; some think that the farthest point south reached by the settlers, as described in the sagas, fits best with Maryland or Virginia, but others contend that the lands about the Gulf of St. Lawrence are more probably designated. The area was named Vinland, as grapes grew there, but it has been suggested that the "grapes" referred to were in fact cranberries. Attempts at colonization were unsuccessful; the Norsemen withdrew; and, although the Greenland colonies lingered on for some four centuries, little knowledge of these first discoveries came down to colour the vision of the seamen of

Cádiz or Bristol; the voyages of Christopher Columbus and John Cabot had their strongest inspirations in quite other traditions.

THE EXPLORATION OF THE COASTLINES OF THE INDIAN OCEAN AND THE CHINA SEA

Trade, across the land bridges and through the gulfs linking those parts of Asia, Africa, and Europe that lie between the Mediterranean and Arabian seas, was actively pursued from very early times. It is therefore not surprising that exploratory voyages early revealed the coastlines of the Indian Ocean. Herodotus wrote of Necho II, king of Egypt in the late 7th and early 6th centuries BC, that "when he stopped digging the canal . . . from the Nile to the Arabian Gulf . . . [he] sent forth Phoenician men in ships ordering them to sail back by the Pillars of Hercules." According to the story, this, in three years, they did. Upon their return, "they told things . . . unbelievable by me," says Herodotus, "namely that in sailing round Libya they had the sun on the right hand." Whatever he thought of the story of the sun, Herodotus was inclined to believe in the voyage: "Libya, that is Africa, shows that it has sea all round except the part that borders on Asia." Strabo records another story with the same theme: one Eudoxus, returning from a voyage to India about 108 BC, was blown far to the south of Cape Guardafui. Where he landed he found a wooden prow with a horse carved on it, and he was told by the Africans that it came from a wrecked ship of men from the west.

The campaigns of Alexander the Great

About 510 BC Darius the Great, king of Persia, sent one of his officers, Scylax of Caria, to explore the Indus. Scylax travelled overland to the Kabul River, reached the Indus, followed it to the sea, sailed westward, and, passing by the Persian Gulf (which was already well known), explored the Red Sea, finally arriving at Arsinoë, near modern Suez. The greater part of the campaigns of the famous conqueror Alexander the Great were military exploratory journeys. The earlier expeditions through Babylonia and Persia were through regions already familiar to the Greeks, but the later ones through the enormous tract of land from the south of the Caspian Sea to the mountains of the Hindu Kush brought the Greeks a great deal of new geographical knowledge. Alexander and his army crossed the mountains to the Indus Valley and then made a westward march from the lower Indus to Susa through the desolate country along the southern edge of the Iranian plateau; Nearchus, his admiral, in command of the naval forces of the expedition, waited for the favourable monsoon and then sailed from the mouth of the Indus to the mouth of the Euphrates, exploring the northern coast of the Persian Gulf on his way.

As Roman power grew, increasing wealth brought increasing demands for Oriental luxuries; this led to great commercial activity in the eastern seas. As the coasts became well known, the seasonal character of the monsoonal winds was skillfully used; the southwest monsoon was long known as Hippalus, named for a sailor who was credited with being the first to sail with it direct from the Gulf of Aden to the coast of the Indian peninsula. During the reign of the Roman emperor Hadrian in the 1st century BC, Western traders reached Siam (now Thailand), Cambodia, Sumatra, and Java; a few also seem to have penetrated northward to the coast of China. In AD 161, according to Chinese records, an "embassy" came from the Roman emperor Marcus Aurelius to the emperor Huan-ti, bearing goods that Huan-ti gratefully received as "tribute." Ptolemy, however, did not know of these voyages: he swept his peninsula of Colmorgo (Malay) southwestward to join the eastward trend of his coast of Africa, thus creating a closed Indian Ocean. He presumably did not believe the story of the circumnavigation of Africa. As the 2nd century AD passed and Roman power declined, trade with the eastern seas did not cease but was gradually taken over by Ethiopians, Parthians, and Arabs. The Arabs, most successful of all, dominated eastern sea routes from the 3rd to the 15th century. In the tales of derring-do of Sindbad the Sailor (a hero of the collection of Arabian tales called *The Thousand and One Nights*), there may be found, behind the fiction, the knowledge of these adventurous Arab sailors and traders, supplying detail to fill in the outline of the geography of the Indian Ocean.

THE LAND ROUTES OF CENTRAL ASIA

The prelude to the Age of Discovery, however, is to be found neither in the Norse explorations in the Atlantic nor in the Arab activities in the Indian Ocean but, rather, in the land journeys of Italian missionaries and merchants that linked the Mediterranean coasts to the China Sea. Cosmas Indicopleustes, an Alexandrian geographer writing in the 6th century, knew that Tzinitza (China) could be reached by sailing eastward, but he added: "One who comes by the overland route from Tzinitza to Persia makes a very short cut." Goods had certainly passed this way since Roman times, but they usually changed hands at many a mart, for disorganized and often warring tribes lived along the routes. In the 13th century the political geography changed. In 1206 a Mongol chief assumed the title of Genghis Khan and, after campaigns in China that gave him control there, turned his conquering armies westward. He and his successors built up an enormous empire until, in the late 13th century, one of them, Kublai Khan, reigned supreme from the Black Sea to the Yellow Sea. Europeans of perspicacity saw the opportunities that friendship with the Mongol power might bring. If Christian Europe could only convert the Mongols, this would at one and the same time heavily tip the scales against Muslim and in favour of Christian power and also give political protection to Christian merchants along the silk routes to the legendary sources of wealth in China. With these opportunities in mind, Pope Innocent IV sent friars to "diligently search out all things that concerned the state of the Tartars" and to exhort them "to give over their bloody slaughter of mankind and to receive the Christian faith." Among others, Giovanni da Pian del Carpini in 1245 and Willem van Ruysbroeck in 1253 went forth to follow these instructions. Travelling the great caravan routes from southern Russia, north of the Caspian and Aral seas and north of the Tien Shan (Tien Mountains), both Carpini and Ruysbroeck eventually reached the court of the emperor at Karakorum. Carpini returned confident that the Emperor was about to become a Christian; Ruysbroeck told of the city in Cathay "having walls of silver and towers of gold"; he had not seen it but had been "credibly informed" of it.

Travels of the Polos

But the greatest of the 13th-century travellers in Asia were the Polos, wealthy merchants of Venice. In 1260 the brothers Nicolo and Maffeo Polo set out on a trading expedition to the Crimea. After two years they were ready to return to Venice, but, finding the way home blocked by war, they travelled eastward to Bukhara (now in Uzbekistan in Central Asia), where they spent another three years. The Polos then accepted an invitation to accompany a party of Tatar envoys returning to the court of Kublai Khan at Cambaluc, near Peking. The Khan received them well, provided them with a gold tablet as a safe-conduct back to Europe, and gave them a letter begging the pope to send "some hundred wise men, learned in the law of Christ and conversant with the seven arts to preach to his people." The Polos arrived home, "having toiled three years on the way," to find that Pope Clement IV was dead. Two years later they set off again, travelling without the wise men but taking with them Nicolo's son, Marco Polo, then a youth of 17. (Marco kept detailed notes of all he saw and, late in life when a captive of the Genoese, dictated to a fellow prisoner a book containing an account of his travels and adventures.) This time the Polos took a different route: starting from the port of Hormuz on the Persian Gulf, they crossed Persia to the Pamirs and then followed a caravan route along the southern edge of the Tarim Basin and Gobi Desert to Cambaluc. Information about the route is interesting, but the great contribution of Marco Polo to the geographical knowledge of the West lay in his vivid descriptions of the East. He had tremendous opportunities of seeing China and appreciating its life, for he was taken into the service of the Khan and was sent as an administrator to great cities, busy ports, and remote provinces, with instructions to write full reports. In his book he described how, upon

every main highroad, at a distance apart of 25 or 30 miles (40 to 50 kilometres), there were stations, with houses of accommodation for travellers, with 400 good horses kept in constant readiness at each station. He also reported that, along the roads, the Great Khan had caused trees to be planted, both to provide shade in summer and to mark the route in winter when the ground was covered with snow. Marco Polo lived and worked in western China, visiting the provinces of Shensi, Szechwan, and Yunnan, as well as the borders of Burma. He frequently visited "the noble and magnificent city of Quinsay [Hang-chou], a name that signifies the Celestial City and which it merits from its pre-eminence to all others in the world in point of grandeur and beauty." Cipango (Japan) he did not visit, but he heard about it from merchants and sailors: "it is situated at a distance of 1,500 miles from the mainland. . . . They have gold in the greatest abundance, its sources being inexhaustible." The most detailed descriptions and the greatest superlatives were reserved for Cambaluc, capital of Cathay, whose splendours were beyond compare; to this city, he said,

> everything that is most rare and valuable in all parts of the world finds its way: . . . for not fewer than 1,000 carriages and pack-horses loaded with raw silk make their daily entry; and gold tissues and silks of various kinds are manufactured to an immense extent.

No wonder that, when Europe learned of these things, it became enthralled. After 17 years, the Venetians were permitted to depart; they returned to Europe by sea. After visiting Java they sailed through the Strait of Malacca (again proving the error of Ptolemy); and, landing at Hormuz, they travelled cross-country to Armenia, and so home to Venice, which they reached in 1295.

Other European travellers in Asia

A few travellers followed the Polos. Giovanni da Montecorvino, a Franciscan friar from Italy, became archbishop of Peking and lived in China from 1294 to 1328. Friar Oderic of Pordenone, an Italian monk, became a missionary, journeying throughout the greater part of Asia between 1316 and 1330. He reached Peking by way of India and Malaya, then travelled by sea to Canton; he returned to Europe by way of Central Asia, visiting Tibet in 1325—the first European to do so. Friar Oderic's account of his journeys had considerable influence in his day: it was from it that the spurious traveller, the English writer Sir John Mandeville, quarried most of his stories.

Ibn Baṭṭūṭah, an Arab of Tangier, journeyed farther perhaps than any other medieval traveller. In 1325 he set out to make the traditional pilgrimage to Mecca, and in some 30 years he visited the greater part of the Old World, covering, it has been said, more than 75,000 miles. He was the first to explore much of Arabia; he travelled extensively in India; he reached Java and Southeast Asia. Then toward the end of his life he returned to the west, where, after visiting Spain, he explored western Sudan "to the northernmost province of the Negroes." He reached the Niger, which he called the Nile, and was astonished by the huge hippopotamuses "taking them to be elephants." When he finally returned to Fès in Morocco he "kissed the hand of the Commander of the Faithful the Sultan . . . and settled down under the wing of his bounty." He wrote a vivid and perspicacious account of his travels, but his book did not become known to Christian Europe for centuries. It was Marco Polo's book that was the most popular of all. Some 138 manuscripts of it survive: it was translated before 1500 into Latin, German, and Spanish, and the first English translation was published in 1577. For centuries Europe's maps of the Far East were based on the information provided by Marco Polo; even as late as 1533 Johannes Schöner, the German maker of globes, wrote:

> Behind the Sinae and the Ceres [legendary cities of Central Asia] . . . many countries were discovered by one Marco Polo . . . and the sea coasts of these countries have now recently again been explored by Columbus and Amerigo Vespucci in navigating the Indian Ocean.

Columbus possessed and annotated a copy of the Latin edition (1483–85) of Marco Polo's book, and in his journal he identified many of his own discoveries with places that Marco Polo describes.

Thus, with Ptolemy in one hand and Marco Polo in the other, the European explorers of the Age of Discovery set forth to try to reach Cathay and Cipango by new ways; Ptolemy promised that the way was short; Marco Polo promised that the reward was great.

The Age of Discovery

In the 100 years from the mid-15th to the mid-16th century, a combination of circumstances stimulated men to seek new routes; and it was new routes rather than new lands that filled the minds of kings and commoners, scholars and seamen. First, toward the end of the 14th century, the vast empire of the Mongols was breaking up; thus, Western merchants could no longer be ensured of safe-conduct along the land routes. Second, the growing power of the Ottoman Turks, who were hostile to Christians, blocked yet more firmly the outlets to the Mediterranean of the ancient sea routes from the East. Third, new nations on the Atlantic shores of Europe were now ready to seek overseas trade and adventure.

THE SEA ROUTE EAST BY SOUTH TO CATHAY

Henry the Navigator

Henry the Navigator, prince of Portugal, initiated the first great enterprise of the Age of Discovery—the search for a sea route east by south to Cathay. His motives were mixed. He was curious about the world; he was interested in new navigational aids and better ship design and was eager to test them; he was also a crusader and hoped that, by sailing south and then east along the coast of Africa, Arab power in North Africa could be attacked from the rear. The promotion of profitable trade was yet another motive; he aimed to divert the Guinea trade in gold and ivory away from its routes across the Sahara to the Moors of Barbary (North Africa) and instead channel it via the sea route to Portugal.

Expedition after expedition was sent forth throughout the 15th century to explore the coast of Africa. In 1445 the Portuguese navigator Dinís Dias reached the mouth of the Sénégal, which "men say comes from the Nile, being one of the most glorious rivers of Earth, flowing from the Garden of Eden and the earthly paradise." Once the desert coast had been passed, the sailors pushed on: in 1455 and 1456 Alvise Ca' da Mosto made voyages to Gambia and the Cape Verde Islands. Prince Henry died in 1460 after a career that had brought the colonization of the Madeira Islands and the Azores and the traversal of the African coast to Sierra Leone. Henry's captain, Diogo Cão, discovered the Congo River in 1482. All seemed promising; trade was good with the riverine peoples, and the coast was trending hopefully eastward. Then the disappointing fact was realized: the head of a great gulf had been reached, and, beyond, the coast seemed to stretch endlessly southward. Yet, when Columbus sought backing for his plan to sail westward across the Atlantic to the Indies, he was refused—"seeing that King John II [of Portugal] ordered the coast of Africa to be explored with the intention of going by that route to India."

The search for routes to Asia

King John II sought to establish two routes: the first, a land and sea route through Egypt and Ethiopia to the Red Sea and the Indian Ocean and, the second, a sea route around the southern shores of Africa, the latter an act of faith, since Ptolemy's map showed a landlocked Indian Ocean. In 1487, a Portuguese emissary, Pêro da Covilhã, successfully followed the first route; but, on returning to Cairo, he reported that, in order to travel to India, the Portuguese "could navigate by their coasts and the seas of Guinea." In the same year another Portuguese navigator, Bartolomeu Dias, found encouraging evidence that this was so. In 1487 he rounded the Cape of Storms in such bad weather that he did not see it, but he satisfied himself that the coast was now trending northeastward; before turning back, he reached the Great Fish River, in what is now South Africa. On the return voyage, he sighted the Cape and set up a pillar upon it to mark its discovery.

The seaway was now open, but eight years were to elapse before it was exploited. In 1492 Columbus had apparently reached the East by a much easier route. By the end of the decade, however, doubts of the validity of Columbus' claim were current. Interest was therefore renewed



World map by J.M. Contarini, 1506, depicting the expanding horizons becoming known to European geographers in the Age of Discovery.
By courtesy of the trustees of the British Museum; photograph, J.R. Freeman & Co. Ltd.

in establishing the sea route south by east to the known riches of India. In 1497 a Portuguese captain, Vasco da Gama, sailed in command of a fleet under instructions to reach Calicut, on India's west coast. This he did after a magnificent voyage around the Cape of Storms (which he renamed the Cape of Good Hope) and along the unknown coast of East Africa. Yet another Portuguese fleet set out in 1500, this one being under the command of Pedro Álvarez Cabral; on the advice of da Gama, Cabral steered southwestward to avoid the calms of the Guinea coast; thus, en route for Calicut, Brazil was discovered. Soon trading depots, known as factories, were built along the African coast, at the strategic entrances to the Red Sea and the Persian Gulf, and along the shores of the Indian peninsula. In 1511 the Portuguese established a base at Malacca (now Melaka, Malaysia), commanding the straits into the China Sea; in 1511 and 1512, the Moluccas, or Spice Islands, and Java were reached; in 1557 the trading port of Macau was founded at the mouth of the Canton River. Europe had arrived in the East. It was in the end the Portuguese, not the Turks, who destroyed the commercial supremacy of the Italian cities, which had been based on a monopoly of Europe's trade with the East by land. But Portugal was soon overextended; it was therefore the Dutch, the English, and the French who in the long run reaped the harvest of Portuguese enterprise.

Some idea of the knowledge that these trading explorers brought to the common store may be gained by a study of contemporary maps. The map of the German Henricus Martellus, published in 1492, shows the shores of North Africa and of the Gulf of Guinea more or less correctly and was probably taken from numerous seamen's charts. The delineation of the west coast of southern Africa from the Guinea Gulf to the Cape suggests a knowledge of the charts of the expedition of Bartolomeu Dias. The coastlines of the Indian Ocean are largely Ptolemaic with two exceptions: first, the Indian Ocean is no longer landlocked; and second, the Malay Peninsula is shown twice—once according to Ptolemy and once again, presumably, according to Marco Polo. The Contarini map of 1506 shows further advances; the shape of Africa is generally accurate, and there is new knowledge of the Indian Ocean, although it is curiously treated. Peninsular India (on which Cananor and Calicut are named) is shown; although too small, it is, however, recognizable. There is even an indication to the east of it of the Bay of Bengal, with a great river running into it. Eastward of this is Ptolemy's India, with the huge island of Taprobane—a muddled representation of the Indian peninsula and Ceylon (now Sri Lanka). East again, as on the map of Henricus Martellus, the Malay Peninsula appears twice. Ptolemy's bonds were hard to break.

THE SEA ROUTE WEST TO CATHAY

It is not known when the idea originated of sailing westward in order to reach Cathay. Many sailors set forth searching for islands in the west; and it was a commonplace among scientists that the east could be reached by sailing west, but to believe this a practicable voyage was an entirely different matter. Christopher Columbus, a Genoese who had settled in Lisbon about 1476, argued that Cipango lay a mere 2,500 nautical miles west of the Canary Islands in the eastern Atlantic. He took 45 instead of 60 nautical miles as the value of a degree; he accepted Ptolemy's exaggerated west–east extent of Asia and then added to it the lands described by Marco Polo, thus reducing the true distance between the Canaries and Cipango by about one-third. He could not convince the Portuguese scientists nor the merchants of Lisbon that his idea was worth backing; but eventually he obtained the support of King Ferdinand and Queen Isabella of Spain.

The sovereigns probably argued that the cost of equipping the expedition would not be very great; the loss, if it failed, could be borne; the gain, should it succeed, was incalculable—indeed, it might divert to Spain all the wealth of Asia.

The voyages of Columbus

On August 3, 1492, Columbus sailed from Palos, Spain, with three small ships manned by Spaniards. From the Canaries he sailed westward, for, on the evidence of the globes and maps in which he had faith, Japan was on the same latitude. If Japan should be missed, Columbus thought that the route adopted would land him, only a little further on, on the coast of China itself. Fair winds favoured him, the sea was calm, and, on October 12, landfall was made on the Bahama island of Guanahaní, which he renamed San Salvador (also called Watling Island, though Samana Cay and other islands have been identified as Guanahaní). With the help of the local Indians, the ships reached Cuba and then Haiti. Although there was no sign of the wealth of the lands of Kublai Khan, Columbus nevertheless seemed convinced that he had reached China, since, according to his reckoning, he was beyond Japan. A second voyage in 1493 and 1494, searching fruitlessly for the court of Kublai Khan, further explored the islands of "the Indies." Doubts seem to have arisen among the would-be colonists as to the identity of the islands since Columbus demanded that all take an oath that Cuba was the southeast promontory of Asia—the Golden Chersonese. On his third voyage, in 1498, Columbus sighted Trinidad, entered the Gulf of Paria, on the coast of what is now Venezuela, and annexed for Spain "a very great continent . . . until today unknown." On a fourth voyage, from 1502 to 1504, he explored the coast of Central America from Honduras to Darien on the Isthmus of Panama, seeking a navigable passage to the west. What passage he had in mind is obscure; if at this point he still believed he had reached Asia, it is conceivable that he sought a way through Ptolemy's Golden Chersonese into the Indian Ocean.

Columbus' tenacity, courage, and skill in navigation make him stand out among the few explorers who have changed substantially ideas about the world. At the time, however, his efforts must have seemed ill-rewarded: he found no emperor's court rich in spices, silks, gold, or precious stones but had to contend with mutinous sailors, dissident colonists, and disappointed sovereigns. He died at Valladolid in 1506. Did he believe to the end that he indeed had reached Cathay, or did he, however dimly, perceive that he had found a New World?

Whatever Columbus thought, it was clear to others that there was much to be investigated, and probably much to be gained, by exploration westward. Not only in Lisbon and Cádiz but also in other Atlantic ports, groups of men congregated in hopes of joining in the search. In England, Bristol, with its western outlook and Icelandic trade, was the port best placed to nurture adventurous seamen. In the latter part of the 15th century, John Cabot, with his wife and three sons, came to Bristol from Genoa or Venice. His project to sail west gained support, and with one small ship, the "Matthew," he set out in May 1497, taking a course due west from Dursey Head, Ireland. His landfall on the other side of the ocean was probably on the northern peninsula of what is now known as Newfoundland. From there, Cabot explored southward, perhaps encouraged to do so, even if seeking a westward passage, by ice in the Strait of Belle Isle. Little is known of John Cabot's first voyage, and almost nothing of his second, in 1498, from which he did not return, but his voyages in high latitudes represented almost as great a navigational feat as those of Columbus.

The coasts between the landfalls of Columbus and of John Cabot were charted in the first quarter of the 16th century by Italian, French, Spanish, and Portuguese sailors. Sebastian Cabot, son of John, gained a great reputation as a navigator and promoter of Atlantic exploration, but whether this was based primarily on his own experience or on the achievements of his father is uncertain. In 1499 Amerigo Vespucci, an Italian merchant living in Seville, together with the Spanish explorer Alonso de Ojeda, explored the north coast of South America from Suriname to the Golfo de Venezuela. His lively and embellished description of these lands became popular, and Waldseemüller, on his map of 1507, gave the name America to the southern part of the continent.

Contarini's map

The 1506 map of Contarini represented a brave attempt to collate the mass of new information, true and false, that accrued from these western voyages. The land explored by Columbus on his third voyage and by Vespucci and de Ojeda in 1499 is shown at the bottom left of the map as a promontory of a great northern bulge of a continent extending far to the south. The northeast coast of Asia at the top left is pulled out into a great peninsula on which is shown a big river and some mountains representing Contarini's concept of Newfoundland and the lands found by the Cabots and others. In the wide sea that separates these northern lands from South America, the West Indies are shown. Halfway between the Indies and the coast of Asia, Japan is drawn. A legend placed between Japan and China reveals the state of opinion among at least some contemporary geographers; it presumably refers to the fourth voyage of Columbus in 1502 and may be an addition to the map. It runs:

> Christopher Columbus, Viceroy of Spain, sailing westwards, reached the Spanish islands after many hardships and dangers. Weighing anchor thence he sailed to the province called Ciambra [a province which then adjoined Cochinchina].

Others did not agree with Contarini's interpretation. To more and more people it was becoming plain that a New World had been found, although for a long time there was little inclination to explore it but instead a great determination to find a way past it to the wealth of Asia. The voyage of the Portuguese navigator Ferdinand Magellan, from 1519 to 1521, dispelled two long-cherished illusions: first, that there was an easy way through the barrier and, second, that, once the barrier was passed, Cathay was near at hand.

Magellan's voyages

Ferdinand Magellan had served in the East Indies as a young man. Familiar with the long sea route to Asia eastward from Europe via the Cape of Good Hope, he was convinced that there must be an easier sea route westward. His plan was in accord with Spanish hopes; five Spanish ships were fitted out in Seville, and in August 1519 they sailed under his command first to the Cape Verde Islands and thence to Brazil. Standing offshore, they then sailed southward along the east coast of South America; the estuary of the Río de la Plata was explored in the vain hope that it might prove to be a strait leading to the Pacific. Magellan's ships then sailed south along the coast of Patagonia. The Gulf of St. George, and doubtless many more small embayments, raised hopes that a strait had been found, only to dash them; at last at Port Julian, at 49°15′ S, winter quarters were established. In September 1520 a southward course was set once more, until, finally, on October 21, Magellan found a strait leading westward. It proved to be an extremely difficult one: it was long, deep, tortuous, rock-walled, and bedevilled by icy squalls and dense fogs. It was a miracle that three of the five ships got through its 325-mile length. After 38 days, they sailed out into the open ocean. Once away from land, the ocean seemed calm enough; Magellan consequently named it the Pacific. The Pacific, however, proved to be of vast extent, and for 14 weeks the little ships sailed on a northwesterly course without encountering land. Short of food and water, the sailors ate sawdust mixed with ship's biscuits and chewed the leather parts of their gear to keep themselves alive. At last, on March 6, 1521, exhausted and scurvy-ridden, they landed at the island of Guam. Ten days later they reached the Philippines, where Magellan was killed in a local quarrel. The survivors, in two ships, sailed on to the Moluccas; thus, sailing westward, they arrived at last in territory already known to the Portuguese sailing eastward. One ship attempted, but failed, to return across the Pacific. The remaining ship, the "Vittoria," laden with spices, under the command of the Spanish navigator Juan Sebastián de Elcano, sailed alone across the Indian Ocean, rounded the Cape of Good Hope, and arrived at Seville on September 9, 1522, with a crew of four Indians and only 17 survivors of the 239 Europeans who had set sail with the expedition three years earlier. Elcano, not having

allowed for the fact that his circumnavigation had caused him to lose a day, was greatly puzzled to find that his carefully kept log was one day out; he was, however, delighted to discover that the cargo that he had brought back more than paid for the expenses of the voyage.

It is fitting to consider this first circumnavigation as marking the close of the Age of Discovery. Magellan and his men had demonstrated that Columbus had discovered a New World and not the route to China and that Columbus' "Indies"—the West Indies—were separated from the East Indies by a vast ocean.

Not all the major problems of world geography were, however, now solved. Two great questions still remained unanswered. Were there "northern passages" between the Atlantic and Pacific oceans more easily navigable than the dangerous Strait of Magellan to the south? Was there a great landmass somewhere in the vastness of the southern oceans—a Terra Australis ("southern land") that would balance the northern continents?

The emergence of the modern world

The centuries that have elapsed since the Age of Discovery have seen the end of dreams of easy routes to the East by the north, the discovery of Australasia and Antarctica in place of Terra Australis Incognita, and the identification of the major features of the continental interiors.

While, as in earlier centuries, traders and missionaries often proved themselves also to be intrepid explorers, in this period of geographical discovery the seeker after knowledge for its own sake played a greater part than ever before.

THE NORTHERN PASSAGES

Roger Barlow, in his *Briefe Summe of Geographie,* written in 1540–41, asserted that "the shortest route, the northern, has been reserved by Divine Providence for England."

The search for a Northeast Passage

The concept of a Northeast Passage was at first favoured by the English: it was thought that, although its entry was in high latitudes, it "turning itself, trendeth towards the southeast . . . and stretcheth directly to Cathay." It was also argued that the cold lands bordering this route would provide a much needed market for English cloth. In 1553 a trading company, later known as the Muscovy Company, was formed with Sebastian Cabot as its governor. Under its auspices numerous expeditions were sent out. In 1553 an expedition set sail under the command of Sir Hugh Willoughby; Willoughby's ship was lost, but the exploration continued under the leadership of its pilot general, Richard Chancellor. Chancellor and his men wintered in the White Sea, and next spring "after much adoe at last came to Mosco." Between 1557 and 1560, another English voyager, Anthony Jenkinson, following up this opening, travelled from the White Sea to Moscow, then to the Caspian, and so on to Bukhara, thus reaching the old east–west trade routes by a new way. Soon, attempts to find a passage to Cathay were replaced by efforts to divert the trade of the ancient silk routes from their traditional outlets on the Black Sea to new northern outlets on the White Sea.

The Dutch next took up the search for the passage. The Dutch navigator William Barents made three expeditions between 1594 and 1597 (when he died in Novaya Zemlya, modern Soviet Union). The English navigator Henry Hudson, in the employ of the Dutch, discovered between 1605 and 1607 that ice blocked the way both east and west of Svalbard (Spitsbergen). Between 1725 and 1729 and from 1734 to 1743, a series of expeditions inspired by the Danish-Russian explorer Vitus Bering attempted the passage from the eastern end, but it was not until 1878–79 that Baron Adolf Erik Nordenskiöld, the Finnish-Swedish scientist and explorer, sailed through it.

The Northwest Passage, on the other hand, also had its strong supporters. In 1576 Humphrey Gilbert, the English soldier and navigator, argued that "Mangia [South China], Quinzay [Hang-chou] and the Moluccas are nearer to us by the North West than by the North East," while John Dee in 1577 set out the view that the Strait of Anian, separating America from Asia, led southwest "along the backeside of Newfoundland." In 1534 Jacques Cartier, the French navigator, explored the St. Lawrence estuary. In 1576 the English explorer Sir Martin Frobisher found the bay named after him. Between 1585 and 1587, the English navigator John Davis explored Cumberland Sound and the western shore of Greenland to 73° N; although he met "a mighty block of ice," he reported that "the passage is most probable and the execution easy." In 1610 Henry Hudson sailed through Hudson Strait to Hudson Bay, confident, before he was set adrift by a mutinous crew, that success was at hand. Between 1612 and 1615, three English voyagers—Robert Bylot, Sir Thomas Button, and William Baffin—thoroughly explored the bay, returning convinced that there was no strait out of it leading westward. As in the quest for a Northeast Passage, interest turned from the search for a route leading to the riches of the East to the exploitation of local resources. Englishmen of the Hudson's Bay Company, founded in 1670 to trade in furs, explored the wide hinterlands of the St. Lawrence estuary and Hudson Bay. Further search for the passage itself did not take place until the 19th century: expeditions led by Sir William Parry (1819–25) and Sir John Franklin (1819–45), as well as more than 40 expeditions sent out to search for Franklin and his party, failed to find the passage. It was left to the Norwegian explorer Roald Amundsen to be the first to sail through the passage, which he did in 1903–05.

EASTWARD VOYAGES TO THE PACIFIC

The discovery of Australia

By the end of the 16th century, Portugal in the East held only the ports of Goa and Diu, in India, and Macau, in China. The English dominated the trade of India, and the Dutch that of the East Indies. It was the Dutch, trading on the fringes of the known world, who were the explorers. Victualling their ships at the Cape, they soon learned that, by sailing east for some 3,000 miles (5,000 kilometres) before turning north, they would encounter favourable winds in setting a course toward the Spice Islands (now the Moluccas). Before long, reports were received of landfalls made on an unknown coast; as early as 1618, a Dutch skipper suggested that "this land is a fit point to be made by ships . . . *in order* to get a fixed course for Java." Thereafter, the west coast of Australia was gradually charted: it was identified by some as the coast of the great southern continent shown on Mercator's map and, by others, as the continent of Loach or Beach mentioned by Marco Polo, interpreted as lying to the south of Malacca (Melaka); Polo, however, was probably describing the Malay Peninsula.

In 1642, a farsighted governor general of the Dutch East India Company, Anthony van Diemen, sent out the Dutch navigator Abel Tasman for the immediate purpose of making an exploratory voyage, but with the ultimate aim of developing trade. Sailing first south then east from Mauritius, Tasman landed on the coast of Tasmania, after which he coasted round the island to the south and, sailing east, discovered the South Island of New Zealand; "we trust that this is the mainland coast of the unknown South land," he wrote. He sailed north without finding Cook Strait, and, making a sweeping arc on his voyage back to the Dutch port of Batavia (now Jakarta, Indonesia), he discovered the Tonga and the Fiji Islands. In 1644, on a second voyage, he traced the north coast of Australia from Cape York (which he thought to be a part of New Guinea) to the North West Cape.

WESTWARD VOYAGES TO THE PACIFIC

The earlier European explorers in the Pacific were primarily in search of trade or booty; the later ones were primarily in search of information.

The traders, for the most part Spaniards, established land portages from harbours on the Caribbean to harbours on the west coast of Central and South America; from the Pacific coast ports of the Americas, they then set a course westward to the Philippines. Many of their ships crossed and recrossed the Pacific without making a landfall; many islands were found, named, and lost, only to be found again without recognition, renamed, and perhaps lost yet again. In the days before longitude could be accurately fixed, such uncertainty was not surprising.

Some voyages—for example, those of Álvaro de Mendaña de Neira, the Spanish explorer, in 1567 and 1568; Mendaña and the Portuguese navigator Pedro Fernández de Quirós in 1595; Quirós and another Portuguese explorer, Luis de Torres, in 1606—had, among other motives, the purpose of finding the great southern continent. Quirós was sure that in Espíritu Santo in the New Hebrides he had found his goal; he "took possession of the site on which is to be founded the New Jerusalem." Torres sailed from there to New Guinea and thence to Manila, in the Philippines. In doing so, he coasted the south shore of New Guinea, sailing through Torres Strait, unaware that another continent lay on his left hand.

The English were rivals of the Spaniards in the search for wealth in unknown lands in the Pacific. Two English seamen, Sir Francis Drake and Thomas Cavendish, circumnavigated the world from west to east in 1577 to 1580 and 1586 to 1588, respectively. One of Drake's avowed objects was the search for Terra Australis. Once he was through Magellan's straits, however, strong winds made him turn north—perhaps not reluctantly. He then sailed along the coast of Peru, surprising and plundering Spanish ships laden with gold, silver, precious stones, and pearls. His fortune made, Drake continued northward perhaps in search of the Northwest Passage. He explored the west coast of North America to 48° N. He returned south to winter in New Albion (California); the next summer he sailed on the Spanish route to Manila, then returned home by the Cape.

Despite the fact that he participated in several buccaneering voyages, the English seaman William Dampier, who was active in the late 17th and early 18th centuries, may be regarded as the first to travel mainly to satisfy scientific curiosity. He wrote: "I was well satisfied enough knowing that, the further we went, the more knowledge and experience I should get, which was the main thing I regarded." His book *A New Voyage Round the World*, published in 1697, further popularized the idea of a great southern continent.

In the late 18th century, the final phase of Pacific exploration occurred. The French sent the explorer Louis-Antoine de Bougainville to the Pacific in 1768. He appears to have been more of a skeptic than many of his contemporaries, for, while he agreed "that it is difficult to conceive such a number of low islands and almost drowned lands without a continent near them," at the same time he maintained that "if any considerable land existed hereabouts we could not fail meeting with it." The British, for their part, commissioned John Byron in 1764 and Samuel Wallis and Phillip Carteret in 1766 "to discover unknown lands and to explore the coast of New Albion." For all the navigational skill and personal endurance shown by captains and crews, the rewards of these voyages in increasing geographical knowledge were not great. The courses sailed were in the familiar waters of the southern tropics; none was through the dangerous waters of higher latitudes.

Cook's voyages in the Pacific

Capt. James Cook, the English navigator, in three magnificent voyages at long last succeeded in demolishing the fables about Pacific geography. He was given command of an expedition to observe the transit of the planet Venus at Tahiti on June 3, 1769; with the observation completed, he carried out his instructions to search the area between 40° and 35° S "until you discover it [Terra Australis] or fall in with the eastern side of the land discovered by Tasman and now called New Zealand." He reached New Zealand, circumnavigated both islands, sailed westward, and on April 19, 1770, made landfall on the eastern coast of Australia. He then turned northward, charting carefully, being well aware of the dangers of the Great Barrier Reef. At Cape York, Cook took possession of the whole eastern coast, to which he gave the name New South Wales. He sailed through Torres Strait, recognizing as he did so that New Guinea was an island. When Cook sailed back to England by Batavia and the Cape, the coastline of the fifth continent was almost complete; only in the south did it still remain unknown. In 1798 to 1799, two British navigators, George Bass and Matthew Flinders, circumnavigated Tasmania, and in 1801–03 Flinders charted the coast of the Great Australian Bight and circumnavigated the continent, thereby proving that there was no strait from the bight to the Gulf of Carpentaria.

In a second voyage, from 1772 to 1775, which in many ways was the greatest of the three, Cook searched systematically for the elusive continent that many still believed might exist. The first summer he examined the area to the south of the Indian Ocean; in the second, he searched the ocean between New Zealand and Cape Horn; and, in the third, the ocean between Cape Horn and the Cape of Good Hope. He sailed home convinced that the great South Pacific continent of the map makers was a fable.

With the exploration of the Pacific completed, interest in a Northwest Passage revived. In 1778 Cook proceeded to latitude 65° N, but he found no way through the ice barrier either to east or to west. He then sailed south to Hawaii, where he was killed in a dispute with the islanders.

Terra Australis Incognita had disappeared: there was now no unknown landmass in the southern oceans. It was Matthew Flinders who suggested that the fifth continent should be named Australia—a name that had long associations with the South Seas and that accorded well with the names of the other continents.

THE CONTINENTAL INTERIORS

At the opening of the 19th century, the major features of Europe, Asia, and North and South America were known; in Africa some classical misconceptions still persisted; inland Australia was still almost blank; and Antarctica was not on the map at all.

Africa. The river systems were the key to African geography. The existence of a great river in the interior of West Africa was known to the Greeks, but in which direction it flowed and whether it found an outlet in the Sénégal, the Gambia, the Congo, or even the Nile were in dispute. A young Scottish surgeon, Mungo Park, was asked to explore it by the African Association of London. In 1796 Park, who had travelled inland from the Gambia, saw "the long sought for majestic Niger flowing slowly *eastwards*." On a second expedition, attempting to follow its course to the mouth, he was drowned near Bussa, in what is now Nigeria. In 1830 an English explorer, Richard Lander, travelled from the Bight of Benin, on the West African coast, to Bussa, and he then navigated the river down to its mouth, which was revealed as being one of the delta distributaries that, because of the trade in palm oil, were known to traders as "the oil rivers" on the Gulf of Guinea.

Exploration of the Zambezi

The Zambezi, in south central Africa, was not known at all until, in the mid-19th century, the Scottish missionary-explorer David Livingstone crossed the Kalahari from the south, found Lake Ngami, and, hearing of populous areas farther north, came upon the river in midcourse. On a great exploratory journey from 1852 to 1856, the main purpose of which was to expose the slave trade, he first travelled upstream, crossed the watershed between the tributaries of the upper Zambezi and those of the lower Congo, and reached the west coast at Luanda, Angola. From there a year's march brought him back to his starting point near the falls that the Africans called "smoke does sound" but that Livingstone prosaically renamed the Victoria Falls; from here he followed the Zambezi downstream, reaching the east coast at Quelimane, in Portuguese East Africa (Mozambique). On his second journey, sent out by the British government to test the navigability of the lower Zambezi, he explored the Shire (Chire) and Rovuma rivers and reached Lake Nyasa. His last journey, from 1865 to 1871, was undertaken at the behest of the president of Britain's Royal Geographical Society (successor to the African Association) "to solve a question of intense geographical interest . . . namely the watershed or watersheds of southern Africa." On this journey Livingstone investigated the complex drainage system between Lake Nyasa and Lake Tanganyika and explored the headwaters of the Congo. He refused to return to England with the Welsh explorer Henry Morton Stanley, who was sent to his rescue in 1871, because he was still uncertain of the position of the watershed between the Nile and the Congo; he wondered if the Lualaba was perhaps a headstream of the



Thomas Kitchin's "New Chart of the World" (published by Laurie and Whittle, London, 1794), illustrating the state of geographical knowledge before the exploration of Antarctica and some of the continental interiors.

By courtesy of the Royal Geographical Society, London, photograph, John Webb

Nile. He struggled back to the maze of waterways around Lake Bangweulu and died there in 1873.

The source of the Nile

The whereabouts of the source of the Nile had intrigued men since the days of the pharaohs. A Scottish explorer, James Bruce, travelling in Ethiopia in 1770, visited the two fountains in Lake Tana, the source of the Blue Nile, first discovered by the Portuguese priest Paez in 1618. The English explorers Richard Burton and John Speke discovered Lake Tanganyika in 1857. Speke then travelled north alone and reached the southern creek of a lake, which he named Victoria Nyanza. Without exploring farther, he returned to England, sure that he had found the source of the Nile. He was right—but he had not seen the outlet, and Burton did not believe him. In 1862 Speke, travelling with the Scottish explorer James Grant, found the Ripon Falls, in Uganda (now submerged following the construction of a dam for Owen Falls hydroelectric station), and "saw without any doubt that Old Father Nile rises in Victoria Nyanza." Stanley completed the puzzle in 1875; he circumnavigated Victoria Nyanza, crossed to the Lualaba, followed that river to the Congo, and then followed the Congo to its mouth. The pattern made by the river systems of Africa was elucidated at last.

Australia. The interior of Australia also posed a problem: was its heart an inland sea or a desert? This question did not arouse anything approaching the same degree of public interest that was taken in the geography of Africa. Exploration was slow; the early settlers on the east coast found that the valleys led to impassable walls at the valley heads. In 1813 the Australian explorer Gregory Blaxland successfully crossed the Blue Mountains by following a ridge instead of taking a valley route. Rivers were found beyond the mountains, but they did not behave as expected. Another explorer, the Australian John Oxley, in 1818 observed: "on every hill a spring, in every valley a rivulet, but the river itself disappears." He guessed that the great fan of rivers that drained the western slopes of the Great Dividing Range of eastern Australia fell into an inland sea. The Australian Charles Sturt resolved the problem by an imaginative journey made in 1829–30. He embarked on the Murrumbidgee River and was "hurried into a great and noble river [the Murray]." A week later he encountered another big river flowing into the Murray from the north, that he rightly concluded was the Darling, the middle course of which he had explored the year before. The voyage ended when he discovered that the Murray drained into Encounter Bay on the south coast. The heart of Australia was not an inland sea but a vast desert. Many more expeditions were needed to map the continent's major features, but two revealed its great extent. In 1840–41 the Australian Edward John Eyre travelled along the south coast from Adelaide to Albany, a distance of more than 1,300 miles (2,100 kilometres); the Australians Robert Burke and William John Wills travelled from Melbourne in the southeast to the Gulf of Carpentaria in the north.

Polar regions. The exploration of the polar regions was the work of the first half of the 20th century. Scientific curiosity mainly inspired the various enterprises, although political rivalry also played some part.

In the North Polar regions, the scientific age began with the voyaging of William Scoresby, an English whaler and scientist, who in 1806 reached 81°21′N. In 1828 an English explorer, Sir William Parry, travelling over drift ice from Svalbard, reached 82° N. The Norwegian explorer Fridtjof Nansen in 1893 attempted to reach the Pole by allowing his ship, the "Fram," to be frozen into the ice in the East Siberian Sea in the hope that a current would carry it over the Pole to east Greenland. At 84° N 102° E, Nansen with a companion left the ship and travelled by sled to 86°13′ N: the ship eventually emerged from the pack ice north of Svalbard. In 1909 an American explorer, Robert Peary, reached the North Pole by journeying by sled with 50 Eskimos from Ellesmere Island, northwest of Greenland. Soundings of 9,000 feet (2,700 metres) were made within five miles (eight kilometres) of the Pole; it seemed, therefore, that there could be no continent here. In 1958 the U.S. submarines "Skate" and "Nautilus" travelled across the Arctic Ocean under the ice cap.

Antarctica

The great southern continent, which Captain Cook demonstrated could not lie in the South Pacific, lay there neglected for some 50 years. From 1839 to 1843, the British rear admiral James Ross, in command of the ships "Erebus" and "Terror," explored the coast of Victoria Land. In 1894 Leonard Christensen, captain of a Norwegian whaler, landed a party at Cape Adare, the first to set foot on Antarctica. In the first decade of the 20th century, various explorers, including Britons such as William Bruce, Robert Falcon Scott, and Sir Ernest Henry Shackleton, the German Erich von Drygalski, and the Frenchman Jean-Baptiste Charcot, confirmed the existence of an ice cap of continental dimensions. In 1908–09 Shackleton led a brilliant expedition, during which he examined the Great Barrier, climbed to 11,000 feet (3,400 metres), and reached 88°23′ S. Scott and his party reached the Pole on January 17, 1912, only to find that the Norwegian explorer Roald Amundsen had already been there on December 14, 1911; Scott's party, caught in a blizzard, died on their return journey. In 1928 Sir Hubert Wilkins, the British explorer and aviator, flew over Grahamland, using Deception Island as a base. In 1957 and 1958 the British explorer Vivian Fuchs and Sir Edmund Hillary, the New Zealand mountaineer, travelled across the continent.

(J.B.Mi.)

EUROPEAN COLONIZATION

The age of modern colonialism began about 1500, following the European discoveries of a sea route around Africa's southern coast (1488) and of America (1492). With these events sea power shifted from the Mediterranean to the Atlantic and to the emerging nation-states of Portugal, Spain, the Dutch Republic, France, and England. By discovery, conquest, and settlement, these nations expanded and colonized throughout the world, spreading European institutions and culture.

European expansion before 1763

ANTECEDENTS OF EUROPEAN EXPANSION

Early communications with the Near East

Medieval Europe was largely self-contained until the First Crusade (1096–99), which opened new political and commercial communications with the Muslim Near East. Although Christian crusading states founded in Palestine and Syria proved ephemeral, commercial relations continued, and the European end of this trade fell largely into the hands of Italian cities.

Early European trade with Asia. The Oriental land and sea routes terminated at ports in the Crimea, until 1461 at Trebizond (now Trabzon, Turkey), Constantinople (now Istanbul), Asiatic Tripoli (in modern Lebanon), Antioch (in modern Turkey), Beirut (in modern Lebanon), and Alexandria (Egypt), where Italian galleys exchanged European for Eastern products.

Competition between Mediterranean nations for control of Asiatic commerce gradually narrowed to a contest between Venice and Genoa, with the former winning when it severely defeated its rival city in 1380; thereafter, in partnership with Egypt, Venice principally dominated the Oriental trade coming via the Indian Ocean and Red Sea to Alexandria.

Overland routes were not wholly closed, but the conquests of the central Asian warrior Timur (Tamerlane)—whose empire broke into warring fragments after his death in 1405—and the advantages of a nearly continuous sea voyage from the Middle and Far East to the Mediterranean gave Venice a virtual monopoly of some Oriental products, principally spices. The word spices then had a loose application and extended to many Oriental luxuries, but the most valuable European imports were pepper, nutmeg, cloves, and cinnamon.

The Venetians distributed these expensive condiments throughout the Mediterranean region and northern Europe; they were shipped to the latter first by pack trains up the Rhône Valley and, after 1314, by Flanders' galleys to the Low Countries, western Germany, France, and England. The fall of Constantinople to the Ottoman Turks in 1453 did not seriously affect Venetian control. Although other Europeans resented this dominance of the trade, even the Portuguese discovery and exploitation of the Cape of Good Hope route could not altogether break it.

Early Renaissance Europe was short of cash money, though it had substantial banks in northern Italy and southern Germany. Florence possessed aggregations of capital, and its Bardi bank in the 14th century and the Medici successor in the 15th financed much of the eastern Mediterranean trade.

Later, during the great discoveries, the Augsburg houses of Fugger and Welser furnished capital for voyages and New World enterprises.

Gold came from Central Africa by Saharan caravan from Upper Volta (Burkina Faso) near the Niger, and interested persons in Portugal knew something of this. When Prince Henry the Navigator undertook sponsorship of Portuguese discovery voyages down the west coast of Africa, a principal motive was to find the mouth of a river to be ascended to these mines.

Technological improvements. Europe had made some progress in discovery before the main age of exploration. The discoveries of the Madeira Islands and the Azores in the 14th century by Genoese seamen could not be followed up immediately, however, because they had been made in galleys built for the Mediterranean and ill suited to ocean travel; the numerous rowers that they required and their lack of substantial holds left only limited room for provisions and cargo. In the early 15th century all-sails vessels, the caravels, largely superseded galleys for Atlantic travel; these were light ships, having usually two but sometimes three masts, ordinarily equipped with lateen sails but occasionally square-rigged. When longer voyages began, the *nao*, or carrack, proved better than the caravel; it had three masts and square rigging and was a rounder, heavier ship, more fitted to cope with ocean winds.

Navigational instruments were improved. The compass, probably imported in primitive form from the Orient, was gradually developed until, by the 15th century, European pilots were using an iron pin that pivoted in a round box. They realized that it did not point to the true north, and no one at that time knew of the magnetic pole, but they learned approximately how to correct the readings. The astrolabe, used for determining latitude by the altitude of stars, had been known since Roman times, but its employment by seafarers was rare, even as late as 1300; it became more common during the next 50 years, though most pilots probably did not possess it and often did not need it because most voyages took place in the narrow waters of the Mediterranean or Baltic or along western European coasts. For longitude, then and many years thereafter, dead reckoning had to be employed, but this could be reasonably accurate when done by experts.

The typical medieval map had been the planisphere, or

Medieval maps

mappemonde, which arranged the three known continents in circular form on a disk surface and illustrated a concept more theological than geographical. The earliest surviving specimens of the portolanic, or harbour-finding, charts date from shortly before 1300 and are of Pisan and Genoese origin. Portolanic maps aided voyagers by showing Mediterranean coastlines with remarkable accuracy, but they gave no attention to hinterlands. As Atlantic sailings increased, the coasts of western Europe and Africa south of the Strait of Gibraltar were shown somewhat correctly, though less so than for the Mediterranean.

THE FIRST EUROPEAN EMPIRES (16TH CENTURY)

Portuguese dominance of Eastern commerce

Portugal's seaborne empire. Following Christopher Columbus' first voyage, the rulers of Portugal and Spain, by the Treaty of Tordesillas (1494), partitioned the non-Christian world between them by an imaginary line in the Atlantic, 370 leagues (about 1,300 miles) west of the Cape Verde Islands. Portugal could claim and occupy everything to the east of the line and Spain everything to the west (though no one then knew where the demarcation would bisect the other side of the globe). Portuguese rule in India, the East Indies, and Brazil rested on this treaty, as well as on Portuguese discoveries and on papal sanction (Pope Leo X, by a bull of 1514, forbade others to interfere with Portugal's possessions). Except for such minor incursions as those of Ferdinand Magellan's surviving ship in 1522 and the Englishman Sir Francis Drake's voyage around the world in 1577–80, the Portuguese operated in the East for nearly a century without European competition. They faced occasional Oriental enemies but weathered these dangers with their superior ships, gunnery, and seamanship.

Territorially, theirs was scarcely an empire; it was a commercial operation based on possession of fortifications and posts strategically situated for trade. This policy was carried out principally by two viceroys, Francisco de Almeida in 1505–09 and Afonso de Albuquerque in 1509–15. Almeida seized several eastern African and Indian points and defeated a Muslim naval coalition off Diu (now in Goa, Daman, and Diu union territory, India). Albuquerque endeavoured to gain a monopoly of European spice trade for his country by sealing off all entrances and exits of the Indian Ocean competing with the Portuguese route around the Cape of Good Hope. In 1510 he took Goa, in western India, which became the capital and stronghold of the Portuguese East, and in 1511 he captured Malacca at the farther end of the ocean. Later he subdued Hormuz (now in Iran), commanding the Persian Gulf. They brought soldiers from the home country in limited numbers; but the Portuguese also relied on alliances with native states and enlisted sepoy troops, a policy later followed by the French and English.

Portugal never fully dominated the Indian Ocean because it lacked warships necessary to control the vast water expanse. Albuquerque's failure to capture Aden at the Red Sea entrance allowed the old traffic through Egypt to Venice to resume following an initial dislocation, and this continued after the Ottoman Turks conquered Egypt in 1517. Much of the Indian Ocean trade was local and, until the Portuguese incursion, had been conducted by Arabs or at least by Muslims. The Portuguese, who at first had intended to oust the Arabs entirely, found it impossible to manage without them. The Hindus, whom they hoped to use for local trade purposes, proved unenterprising and had caste restrictions regarding sea voyages. Muslims were soon trafficking again vigorously, with Portuguese sanction.

Portuguese subjects also pressed beyond the Strait of Malacca to the East Indies, Siam (now Thailand), and Canton in Ming-dynasty China. Trade with the celestial empire, difficult at first because of China's exclusionist policies, at length grew, especially after Portugal in 1557 leased Macau, through which for the next 300 years passed much of the Occidental trade with China. Individual Portuguese reached Japan in 1542, followed by traders and Francis Xavier (later made a saint), a renowned Jesuit missionary who laboured with small success to make converts. In the 17th century, the Japanese adopted a rigorous exclusionist policy, although they allowed Portugal's successors, the Dutch, to conduct a limited trade from the small island of Deshima, near Nagasaki.

Partial domination of the Indian Ocean and much of its valuable trade did not bring Portugal's crown as much profit as had been anticipated. The intention had been to make Oriental trade a royal monopoly; but Portuguese, from viceroys to humble soldiers and seamen, became private merchants and lined their own pockets to the deprivation of the royal treasury. The Eastern footholds were expensive to maintain, and frequent mishaps to vessels of the Indian fleets, from shipwreck or enemies, reduced gains. The lack of a true monopoly prevented the Portuguese from charging the prices that they wished in European markets. Moreover, Lisbon, while an ideal starting point for voyages around the Cape, proved poorly situated as a distribution centre for spice to northern and central Europe. Antwerp, on the Scheldt, was far superior, and for a time Portugal maintained a trading house there; but Portuguese agents found spice sales taken out of their hands by more experienced Italian, German, and Flemish merchants, and the Antwerp establishment was closed in 1549.

It has been asserted that the Portuguese had no racial prejudice, but their record proves the opposite. In the 16th and 17th centuries, they could not be expected to be tolerant of Oriental religions, although they soon recognized that wholesale conversion to Catholicism was impossible. Some Africans and Asiatics became Christians and even entered the clergy; but seldom if ever did they rise above the status of parish priests. In other affairs the Portuguese generally treated the dark-skinned peoples as inferiors.

The east coast of Brazil belonged to Portugal by the Tordesillas pact. The government of Manuel I and his successor, John III (ruled 1521–57), paid it small attention for 30 years. It proved nearly useless as a way station to the Cape; its Indian population was savage, and its products, consisting chiefly of *pau-brasil* (Brazilian dyewood), yielded much less revenue than those of India. Threats of French and Spanish intrusion caused John III, in 1530, to send Martim Afonso de Sousa to make a careful survey of the Brazilian coast and to suggest sites for colonization. Next, the littoral was partitioned into strips called *capitanias,* each colonized and governed under feudal terms by a proprietor, or *donatário.* Some limited settlement followed, and in 1549 the *capitanias* were united under a governor general who established residence at Bahia (now Salvador, Brazil).

Portuguese colonization of Brazil

In 1580 Philip II of Spain seized the Portuguese throne, which had fallen vacant and to which he had some blood claim. Portugal remained theoretically independent, bound only by a personal union to its neighbour; but succeeding Spanish monarchs steadily encroached on its liberties until the small kingdom became, in effect, a conquered province. Spain's European enemies meanwhile descended on the Portuguese Empire and ended its Eastern supremacy before the restoration of Portugal's independence in 1640.

Beginnings of the Spanish conquest in America

Spain's American empire. *The conquests.* Only gradually did the Spaniards realize the possibilities of America. They had completed the occupation of the larger West Indian islands by 1512, though they largely ignored the smaller ones, to their ultimate regret. Thus far they had found lands nearly empty of treasure, populated by naked primitives who died off rapidly on contact with Europeans. In 1508 an expedition did leave Hispaniola to colonize the mainland, and, after hardship and decimation, the remnant settled at Darién on the Isthmus of Panama, from which in 1513 Vasco Núñez de Balboa made his famous march to the Pacific. On the Isthmus the Spaniards heard garbled reports of the wealth and splendour of Inca Peru. Balboa was succeeded (and judicially murdered) by Pedrarias Dávila, who turned his attention to Central America and founded Nicaragua.

Expeditions sent by Diego Velázquez, governor of Cuba, made contact with the decayed Mayan civilization of Yucatán and brought news of the cities and precious metals of Aztec Mexico. Hernán Cortés entered Mexico from Cuba in 1519 and spent two years overthrowing the Aztec confederation, which dominated Mexico's civilized heart-

land. The Spaniards used firearms effectively but did most of their fighting with pikes and blades, aided by numerous Indian allies who hated the dominant Aztecs. The conquest of Aztec Mexico led directly to that of Guatemala and about half of Yucatán, whose geography and warlike inhabitants slowed Spanish progress.

Mexico yielded much gold and silver, and the conquerors imagined still greater wealth and wonders to the north. None of this existed, but it seemed real when a northern wanderer, Alvar Núñez Cabeza de Vaca, in 1536 brought to Mexico an exciting but fanciful report of the fabulous lands. Expeditions explored northern Mexico and the southern part of what is now the United States—notably the expedition of Juan Rodríguez Cabrillo by sea along what are now the California and Oregon coasts and the expeditions of Hernando de Soto and Francisco Vázquez Coronado through the southeastern and southwestern U.S. regions. These brought geographical knowledge but nothing of value to the Spaniards, who for years thereafter ignored the northern regions.

Meanwhile, the Pizarro brothers—Francisco Pizarro and his half-brothers Gonzalo and Hernando—entered the Inca Empire from Panama in 1531 and proceeded with its conquest. Finding the huge realm divided by a recent civil war over the throne, they captured and executed the incumbent usurper, Atahualpa. But the conquest took years to complete; the Pizarros had to crush a formidable native rising and to defeat their erstwhile associate, Diego de Almagro, who felt cheated of his fair share of the spoils. The Pizarros and their followers took and divided a great amount of gold and silver, with prospects of more from the mines of Peru and Bolivia. By-products of the Inca conquest were the seizure of northern Chile by Pedro de Valdivia and the descent of the entire Amazon by Francisco de Orellana. Other conquistadors entered the regions of what became Ecuador, Colombia, and Argentina. (See LATIN AMERICA, THE HISTORY OF.)

A colonial period of nearly three centuries followed the major Spanish conquests. The empire was created in a time of rising European absolutism, which flourished in both Spain and Spanish America and reached its height in the 18th century. The overseas colonies became and remained the king's private estate.

Spanish colonial policies. Shortly before the death of Queen Isabella I in 1504, the Spanish sovereigns created the House of Trade (Casa de Contratación) to regulate commerce between Spain and the New World. Their purpose was to make the trade monopolistic and thus pour the maximum amount of bullion into the royal treasury. This policy, seemingly successful at first, fell short later because Spain failed to provide necessary manufactured goods for its colonies, foreign competitors appeared, and smuggling grew.

In 1524 Charles V created the Council of the Indies (Consejo de Indias) as a lawmaking body for the colonies. During the three centuries of its existence, this council enacted a massive amount of legislation, though much grew obsolete and became a dead letter. The industrious Philip II died in 1598, and his indolent or incompetent successors left American affairs to the Casa and Consejo; both proved generally conscientious and hard-working bodies, though, for a time in the 17th century, appointments to the legislating council could be purchased.

The viceregal system

The viceregal system dated from 1535, when Antonio de Mendoza was sent to govern New Spain, or Mexico, bypassing the still-vigorous Cortés. A second viceroy was named for Peru in 1542, and the viceroyalties of New Granada and Río de la Plata were formed in 1739 and 1776, respectively. By the 18th century, viceroys served average terms of five years, and under them functioned a hierarchy of bureaucrats, nearly all sent from Spain to occupy frequently lucrative posts. American-born Spaniards resented this favouritism shown the peninsular Spaniards, and their jealousy accounted in part for their later separation from Spain. Lower socially and economically than either white class were the mestizo offspring of white and Indian matings, and still lower were the Indians and black slaves.

Though a belief to the contrary exists, Spain sent many colonists to America. One indication of this is the number of new cities founded, distinct from the old Indian culture centres. A partial list of such cities, besides the early island ones, includes Vera Cruz, New Spain; Panama, Cartagena, and Guayaquil, in New Granada (in modern Panama, Colombia, and Ecuador, respectively); Lima, Peru; and all those of what are now Chile, Paraguay, Argentina, and Uruguay.

A problem early faced and never truly solved by Spain was that of the Indians. The home government was generally benevolent in legislating for their welfare but could not altogether enforce its humane policies in distant America. The foremost controversy in early decades involved the *encomienda,* by which Indian groups were entrusted to Spanish proprietors, who in theory cared for them physically and spiritually in return for rights to tribute and labour but who in practice often abused and enslaved them.

Spanish Dominican friars were the first to condemn the *encomienda* and work for its abolition; the outstanding reformer was a missionary, Bartolomé de Las Casas, who devoted most of his long life to the Indian cause. He secured passage of laws in 1542 ordering the early abolition of the *encomienda,* but efforts to enforce these brought noncompliance in New Spain and armed rebellion in Peru. A belief held by some Spanish theologians—that Indians were inferior beings who were destined to be natural slaves, to be subdued and forcibly converted to Christianity—generally prevailed over the opposition of Las Casas and fellow Dominicans. The *encomienda* or its equivalent endured, although this feudal institution declined as royal absolutism grew.

Diminution of the Indians

The Indians became real or nominal Christians, but their numbers shrank, less from slaughter and exploitation than from Old World diseases, frequently smallpox, for which they had no inherited immunity. The aboriginal West Indian population virtually disappeared in a few generations, to be replaced by black slaves. Indian numbers shrank in all mainland areas: at the beginning of Spanish settlement there were perhaps 50,000,000 aborigines; the figure had decreased to an estimated 4,000,000 in the 17th century, after which it slowly rose again. Meanwhile the hybrid mestizo element grew and—to a limited extent—replaced the Indians.

The Leyenda Negra (Black Legend) propagated by critics of Spanish policy still contributes to the general belief that Spain exceeded other nations in cruelty to subject populations; on the other hand, a review of Spain's record suggests that it was no worse than other nations and, in fact, produced a greater number of humanitarian reformers. When Dominican zeal declined, the new and powerful Jesuit order became the major Indian protector and led in missionary activity until its expulsion from the Spanish Empire in 1767; the Jesuits took charge of large converted native communities, notably in the area of the viceroyalty of Río de la Plata that is now Paraguay, in their paternalism often imposing stern discipline.

Effects of the discoveries and empires. Before the discovery of America and the sea route to Asia, the Mediterranean had been the trading and naval centre of Europe and the Near East. Italian seamen were rightly considered to be the best, and they commanded the first royally sponsored transatlantic expeditions—Columbus for Spain, John Cabot for England, and Giovanni da Verrazano for France.

Europe's shift to the Atlantic. Until then the Western countries had lain on the fringe of civilization, with nothing apparently beyond them but Iceland and small islands. With the discovery of the Cape route and America, nations formerly peripheral found themselves central, with geographical forces impelling them to leadership.

The Mediterranean did not become a backwater, and the Venetian republic remained a major commercial power in the 16th century. Venice's decline came in the 17th, though the Venetians were still formidable against the Turks. As the more powerful Dutch, French, and English replaced the Eastern pioneers of Portugal, however, the burden of competition became more than the venerable republic could bear. The last decisive naval battle fought

wholly by Mediterranean seamen was Lepanto (Náupaktos, Greece), where Don John of Austria, in 1571, commanding Spanish and Italian galleys, defeated an Ottoman fleet. Although Atlantic powers thereafter often fought in the Mediterranean, they mainly fought each other, while the Italian cities became pawns in international politics. The nation-state was superseding the small principality and city-state, a trend that had begun before the discoveries. The new nations lay on the Atlantic; and, though Spain and France had Mediterranean frontages, the advantage went to those seaports belonging to substantial countries with ready access to the outer world.

Changes in Europe. The opening of old lands in Asia and new ones in America changed Europe forever, and the Iberian countries understandably felt the changes first. The Portuguese government, for a time, made large profits from its Eastern trade, and individuals prospered; but Oriental luxuries were costly compared with the European goods that Portugal offered, and the balance had to be made up in specie. This eastward drain of gold and silver had gone on long before Portuguese imperial times, but it was now intensified. Much of the bullion reaching the Orient did not circulate but was hoarded or made into ornaments; consequently, there was no inflation in Asia, and prices there did not rise enough to create a demand for Western goods, which would have reversed the flow of bullion from the West. The Portuguese obtained most of the precious metal for this trade from spice sales through Antwerp and from Africa. The drain proved critical, and, by the reign of John III, the government found itself hard pressed economically and forced to abandon overseas posts that were a financial burden. Later, beginning in the 17th century, Portugal drew its own supply of jewels and gold from Brazil.

Eastward drain of Portuguese gold and silver

Spain's case was the reverse; although the first American lands discovered yielded little mineral wealth, the mines of Mexico by the 1520s and those of Potosí (in modern Bolivia) by the 1540s were shipping to Spain large quantities of bullion, much of it crown revenue. This did not furnish Charles V and Philip II their largest income; Spanish taxation still exceeded wealth from the New World, yet American silver and gold proved sufficient to cause a price revolution in Spain, where costs, depending on the region, were multiplied by three and five during the 16th century. The Spanish government wished to keep bullion from leaving the kingdom, but high prices in Spain made it a good market for outside products. Spanish industry declined in the 16th century, in part because of the sales taxes imposed by the crown, which necessitated more buying of foreign merchandise. Great quantities of bullion had to be poured out to finance the expensive Spanish European empire and the costly wars and diplomacy of Charles V and Philip II, both of whom were constantly in debt.

Price rises followed in other countries, largely from the influx of Spanish bullion. In England, where some statistics are available, costs by 1650 had risen by 250 percent over those of 1500.

The European commercial revolution, which brought increased industry, more trade, and larger banks, had begun before the discoveries, but it received stimulus from them. Bullion from America helped create a money economy, replacing the older and largely barter exchange—a trend accentuated by greater European mineral production in the early 16th century. The trade emporiums of Italy and the Baltic Hanseatic League declined and were largely replaced by those of the Dutch Republic, England, and France. Joint-stock companies made an impressive appearance, notably the East India Companies of the Dutch Republic, England, and France in the 17th century. The mercantile theory that precious metals constitute the true wealth, though it had attracted advocates for a long time, now came into vogue and continued to dominate economic thinking.

New products for Europe

Discovery introduced Europe to new foods and beverages. Coffee, from Ethiopia, had been consumed in Arabia and Egypt before its wide European use began in the 17th century. Tobacco, an American plant smoked by Indians, won an Old World market despite many individual objectors; the same proved true of chocolate from Mexico and tea from Asia. The South American potato became a staple food in such places as Ireland and central Europe. Cotton, from the Old World, took firm root in the New, from which Europe received an enormously increased supply. Sugar, introduced to the American tropics, along with its molasses and rum derivatives, in time became the principal exports of those regions. Spice was certainly more plentiful than before the discoveries, though the Dutch, when they controlled the East Indies, were able to limit production and thus to keep the price of cloves and nutmegs high.

The influence of the discoveries permeated literature. Sir Thomas More's *Utopia,* printed in 1516 and dealing with an imaginary island, was suggested by South America. The Portuguese poet Luís de Camões recounted the voyage of Vasco da Gama, though fancifully, in epic verse. Michel de Montaigne discoursed upon American savages, some of whom he had seen in France. Christopher Marlowe's drama *Tamburlaine* (1587), though based on the life of the Asiatic conqueror, was an exhortation to his fellow Englishmen to penetrate the New World.

Historiography acquired a broader base by taking the newly discovered lands into account. Astronomy was revolutionized by European penetration of the Southern Hemisphere and discovery of constellations unknown before. Map makers, typified by the Fleming Gerardus Mercator and the Dutchman Abraham Ortelius, portrayed the world in terms that are still recognizable.

COLONIES FROM NORTHERN EUROPE AND MERCANTILISM (17TH CENTURY)

The northern Atlantic powers, for understandable reasons, acquired no permanent overseas possessions before 1600. The United Provinces of the Netherlands spent the final decades of the 16th century winning independence from Spain; France had constant European involvements and wars of religion; England, matrimonially allied with Spain as late as 1558, was undergoing its Protestant Reformation and long was unwilling to challenge predominant Spain openly in any manner.

The Dutch. Although England's defeat of Philip II's Armada in 1588 helped to lessen Spanish sea power, it was the Dutch who early in the next century really broke that power and became the world's foremost naval and commercial nation, with science and skills commensurate with their prowess. Only late in the 17th century did they decline, because of Holland's limited size and the inferiority of its geographical position to England's. The Dutch, meanwhile, penetrated all the known oceans, including the Arctic, and waged unrelenting war against the Iberian kingdoms.

The Dutch coveted the Portuguese commercial empire more than the Spanish continental one. They took much of the Portuguese East and invaded Brazil (1624–54), the richer half of which they controlled for a time. They also penetrated Portuguese Angola, which they desired because the slaves it exported were beginning to work the Brazilian plantations. They ultimately failed in the South Atlantic, though they gained Dutch Guiana (now Suriname), Curaçao, and what later became British Guiana (Guyana). Meanwhile, Willem Schouten, one of their free-lance voyagers, had made the discovery of Cape Horn in 1616.

Eastern pursuits. The Dutch States-General, in 1602, chartered the United East India Company (Vereenigde Oost-Indische Compagnie, popularly called the Dutch East India Company), a joint-stock enterprise with investment open to all. In control was a board of 17 directors, the so-called Heeren XVII, who received a monopoly of navigational rights eastward around the Cape of Good Hope and westward through the Strait of Magellan. They could make treaties with native princes on behalf of the States-General (from which they were scarcely separable), establish garrisoned forts, and appoint governors and justices. The company had no interest in extending Protestantism, and there was no mention of religious conversion, though Calvinist ministers later gained converts in the East, mostly in communities previously made Catholic by Portuguese Jesuits.

Formation of the United East India Company

The company established headquarters first at Bantam in Java in 1607, later moving them to Jacatra, renamed Batavia (now Jakarta), in the same island. Its two main objectives were the ouster of European competitors—Portuguese, English, and Spanish—and dominance of local trade, previously in native hands. Portuguese vigour had somewhat declined, and the Dutch were victorious in most armed encounters. They also squeezed out the English, whose own East India Company thereafter concentrated efforts in the Indian peninsula.

The principal builder of the Dutch Oriental empire was Jan Pieterszoon Coen, company governor general from 1618 to 1623 and again from 1627 until his death in 1629. Financially, local trade monopoly was even more important than the expulsion of white competitors. The extension of Dutch control to islands beyond Java had started before the governorship of Coen, who accentuated the process. He and other company officials behaved ruthlessly; for example, when the inhabitants of the nutmeg-growing island of Great Banda (modern Pulau Banda Besar in Indonesia) resisted the Dutch in 1621, Coen had 2,500 of the inhabitants massacred and 800 more transported to Batavia. Company policy was to restrict clove production to Amboina and a few neighbouring islands firmly under Dutch control. To insure this, about 65,000 clove trees were destroyed in the Moluccas, and Dutch subjection of Macassar made the monopoly virtually complete. In 1656 the famous Moluccas were described as a wilderness. Besides being a conqueror, Coen was an able businessman and an economist. When he died he was engaged in gaining a monopoly of the pepper of interior Sumatra, which was later sealed off securely by the fall of Portuguese Malacca in 1641.

Batavia as the focal point of the Dutch East

Batavia became the focal point of the Dutch East, and through it passed the commerce of China, Japan, India, Ceylon, and Persia, bound for Europe or other Oriental ports. The Dutch never monopolized the China trade because the Portuguese held Macau, the Spaniards held Manila, and the Japanese, for a time, engaged in this commerce. The Dutch gained a foothold in Formosa in 1624 but lost it to a Chinese pirate in 1662. After Japan became exclusionist in 1641, a trickle of Dutch trade continued to enter it through the small island of Deshima (now part of Nagasaki, Japan), even after the dissolution of the United East India Company in 1799.

The economy of Java changed somewhat after the importation of the coffee plant in 1696. Coffee, often simply called java, rapidly became a major island crop and was exported from there to Dutch America. The company had earlier brought coffee to Ceylon (now Sri Lanka), but that experiment had failed when a blight attacked its leaves. The company ousted the Portuguese from Ceylon and dominated the island until it was itself dispossessed by the British in 1796. Under its jurisdiction, as earlier, the major Ceylonese export was cinnamon, though the Dutch also dealt in jewels and pepper and carried on a trade in elephants.

In their constant search for commercial outlets, the company's officials sponsored new exploration. Coen's ablest successor, Antonio van Diemen, governor general in 1636–45, sent Abel Tasman to investigate the great land (Australia) previously sighted by Spanish, Portuguese, and Dutch seamen. Tasman sailed around the continent and discovered Van Diemen's Land (Tasmania), Staatenland (New Zealand), and the Tonga and Fiji Islands, but their commercial possibilities seemed insufficient to warrant further attention.

Dutch penetration of the East was not colonization; small farmers and artisans neither could nor would compete with the abundant, cheap native labour. Those Dutchmen going eastward were company officials, seamen and soldiers, overseers of plantations and commerce, and a few scientists and Calvinist clergymen; there was no place for others.

The Dutch moved into uninhabited Mauritius, which they later abandoned and saw pass first to France and finally to Great Britain. The Heeren XVII felt the need of a station on the arduous voyage between the home country and the East. They obtained it at Cape Town (founded in 1652 by Jan van Riebeeck), which company ships thereafter regularly visited for fresh meat and vegetables to reduce scurvy. The town did not altogether live up to first expectations because the harbour was exposed, but the hinterland possessed a good climate and no dangerous natives. Beginning in the 1680s the company encouraged a moderate influx by Dutch families and French Huguenot exiles. Although the British conquered the colony in 1806, the descendants of these early settlers remained the largest white element and spoke a variant of Dutch, which became Afrikaans.

Western pursuits. Dutch activity in the South Atlantic, Guyana, the West Indies, and New Netherland (New York) was the work of the West India Company (West-Indische Compagnie), founded in 1621. This never proved as successful as the Heeren XVII's generally profitable enterprise, but it did produce results. Except for the Cape, the only real Dutch colonization undertaking was New Netherland in North America, started in 1624 by the West India Company. Ft. Amsterdam, or New Amsterdam, was founded, and two years later the company agent Peter Minuit made a 60-guilder ($24) transaction with the local Indians for the purchase of Manhattan island. Dutch settlement along the Hudson from New Amsterdam to Ft. Orange (Albany) remained sparse; the company's insistence on monopolizing the Indian fur trade discouraged Dutchmen from migrating there. Further, the policy of creating large patroon land grants, five in all, along the river under feudal proprietors, limited settlement. New Amsterdam itself became fairly thriving because it possessed the best harbour in North America. Many besides Dutchmen settled there; some came from nearby New England, and there was a sprinkling of French, Scandinavian, Irish, German, and Jewish inhabitants. The city was weakly defended and fell rather easily to an English fleet in 1664; it was renamed New York. Although the Dutch retook it briefly in 1673–74, the colony became permanently English by the Treaty of Westminster in 1674. The West India Company was then dissolved, to be reconstituted for exploitation of the Caribbean holdings but to attempt no further territorial expansion.

Founding of the Dutch West India Company

The French. France probably could have become the leading European colonial power in the 17th and 18th centuries. It had the largest population and wealth, the best army while Louis XIV ruled, and, for a time in his reign, the strongest navy. But France pursued a spasmodic overseas policy because of an intense preoccupation with European affairs; England, France's ultimately successful rival, was freer of such entanglements.

Early settlements in the New World. Verrazano reconnoitered the North American coast for France in 1524, and in the next decade Jacques Cartier explored the St. Lawrence River; his plans to establish a colony, however, came to nothing. During most of the rest of the 16th century, French colonization efforts were confined to short-lived settlements at Guanabara Bay (Rio de Janeiro) and Florida; both met sad ends. France meanwhile was troubled by internal religious strife and, for a time, was influenced by Philip II of Spain. But at the beginning of the 17th century, with Spanish power declining and domestic religious peace restored by King Henry IV's Edict of Nantes (1598), granting religious liberty to the Huguenots, the King chartered a Compagnie d'Occident (Western Company). This led to further exploration and to a small Acadian (Nova Scotian) settlement, and in 1603 Samuel de Champlain went to Canada, called New France. Champlain became Canada's outstanding leader, founding Quebec in 1608, defeating the Iroquois of New York, stimulating fur trade, and exploring westward to Lake Huron in 1615. He introduced Recollet (Franciscan) friars for conversion of the American Indians, but the Jesuit order (the Society of Jesus) soon became the principal missionary body in Canada.

Under the ministership of Cardinal Richelieu (served 1624–42), a Council of Marine was created, with responsibility for colonial affairs. French West Indian settlement, following the activities of pirates and filibusters, began in 1625 with the admission of French settlers to St. Christopher (already settled by the British in 1623 and partitioned

French West Indian settlement

between the two countries until its cession to the British in 1713), and by 1664 France held 14 Antillean islands containing 7,000 whites, the principal possessions being Guadeloupe and Martinique. Saint-Domingue (Haiti), not yet annexed, contained numbers of Frenchmen, mostly buccaneers from Tortuga. Sugar became the main crop of the islands; the date when importation of black slaves began is uncertain, though some were sold at Guadeloupe as early as 1642.

French West Indian society was caste bound, with officials and large planters (*gros blancs*) at the top, followed, in descending order, by merchants, buccaneers, and small farmers (*petits blancs*). Lowest of all were contract labourers from France (*engagés*) and black slaves.

French Guiana was built around the Cayenne settlement, founded about 1637. There were other Frenchmen along the neighbouring coast at first, but, threatened by Dutchmen and natives, they finally took refuge at Cayenne. The Cayenne settlers, lacking any basis of prosperity, existed partly by raiding the Amazon Indians. The 18th century brought some improvement, but as late as 1743 French Guiana had only 600 whites, living by coffee and cacao culture and without means to import any but the crudest necessities.

Activities in India. Jean-Baptiste Colbert held a succession of high offices in France, including the ministry of marine, during the early reign of Louis XIV. Colbert was an archmercantilist and believed that an abundance of precious metals would enrich France. This required a favourable balance of trade and protective tariffs. Most of his policy applied to France itself, but he meant to supplement it with colonial markets protected by a strong navy. Colbert felt concern over the quantities of cash that Frenchmen paid the Dutch for Eastern products and intended for his countrymen to have a share of those profits. In 1664 he placed hopes in a new French Company of the East Indies (Compagnie Française des Indes Orientales), to which he personally subscribed and which bought out small predecessors. The company tried unsuccessfully to make Madagascar a great centre of trade, and the huge island became a stronghold of piracy, though the French acquired nearby Mauritius.

In the Indian peninsula, where the English East India Company had holdings, French progress was slow in Colbert's time and after, partly because the last great Mughal emperor, Aurangzeb, reigned and dominated India. The company did acquire Pondichéry and several other posts, however, and an affiliate opened a limited trade with China. When Aurangzeb died in 1707, his empire declined rapidly. Thereafter, the question of future control of India lay chiefly between the French company (reorganized and renamed the Compagnie Française des Indes in 1720) and the English company; both companies backed or opposed warring native rulers and exacted payment from them for financial support and for arming and drilling the native sepoy troops in the European manner. By the 1740s the French had gained the upper hand, and in the War of the Austrian Succession (1740–48; called King George's War in North America), the French governor general of India, Joseph-François Dupleix, captured Madras, the centre of British power. But in the ensuing Treaty of Aix-la-Chapelle the British, who had made gains in North America, recovered Madras. Never again did the French come so near success, and their fortunes soon declined. Their company had not made large profits because expensive wars and the costs of subsidizing native princes had consumed revenue. The home government seldom cooperated, and French investors on the whole declined to speculate in overseas ventures.

French and English rivalry

Colonization of New France. New France became a royal province in 1663, with both good and bad results. The arrival of troops in 1665 lessened the danger from the hostile Iroquois. Jean Talon, the powerful intendant sent by Colbert in the same year, strove to make Canada a self-sustaining economic structure, but his plan was finally thwarted by his home government's failure to supply fi-



European expansion, 1600–1700.

nancial means chiefly because of the King's extravagance and costly European wars.

Colbert gave some stimulus to colonization of New France. Grants of land, called *seigneuries,* with frontages on the St. Lawrence, were apportioned to proprietors, who then allotted holdings to small farmers, or habitants. More land came under cultivation, and the white population grew, though immigration from France declined sharply after 1681 because the home authorities were reluctant to spare manpower for empty Canada. After 1700 most French Canadians were North American born, a factor that weakened loyalty to the mother country.

North American exploration proceeded rapidly in Colbert's time. Fur traders had earlier reached Lake Superior; Louis Jolliet and Jacques Marquette now travelled the Fox and Wisconsin rivers to the Mississippi in 1673 and descended it to the Arkansas. Robert Cavelier, sieur de La Salle, followed the Mississippi to the Gulf of Mexico in 1682 and claimed the entire Mississippi River Basin, or Louisiana, for France; a later consequence was the founding of New Orleans (Nouvelle-Orléans) in 1718 by Jean-Baptiste Lemoyne, sieur de Bienville, the governor of Louisiana. French traders ultimately reached Santa Fe in Spanish New Mexico, and the sons of explorer Pierre Gaultier de Varennes, sieur de la Vérendrye—Louis-Joseph and François—visited the Black Hills of South Dakota and may have seen the Rocky Mountains.

The Roman Catholic Church became firmly rooted in Canada, without the intellectual opposition and anticlericalism that developed in 18th-century France. Jesuit mission work among the Indians, extending to the Middle West, saw more devotion and bravery by the priests than substantial results. Christianity made small appeal to most Indians, who could accept a supreme being but rejected the Christian ethic. Several zealous Jesuits became martyrs to the faith; genuine conversions were few and backslidings frequent.

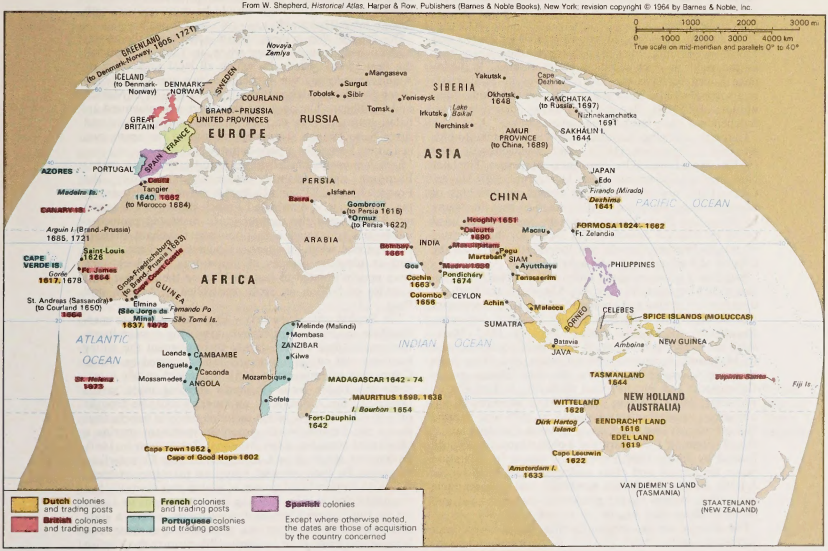
Jesuit mission work

In the 18th century, with the pioneering period over, life in New France became easygoing and even pleasant, despite governmental absolutism. But the fur trade in the west drew vigorous young men from the seigneurial estates to become *coureurs de bois* (fur traders), and their loss crippled agriculture. Civil and religious authorities tried to hold settlers to farming because furs paid neither tithes nor seigneurial dues. This drainage of manpower partly explains the slow growth of New France, which, by a census of 1754, had only 55,000 whites.

The English. There is evidence that Bristol seamen reached Newfoundland before 1497, but John Cabot's Atlantic crossing in that year is the first recorded English exploration. After the death of Henry VII in 1509, England lost interest in discovery and did not resume it until 1553 and the formation of the Muscovy Company, which tried to find a Northeast Passage to Asia, discovered the island of Novaya Zemlya, and opened a small trade with Russia. The English also searched for a Northwest Passage, and Martin Frobisher sailed to Greenland, Baffin Island, and the adjacent mainland.

English ascendancy in India. Francis Drake and others raided the Spanish Main, and Drake and Thomas Cavendish sailed around the world. The defeat of Philip II's Armada in 1588, though less disastrous to Spain's seapower than commonly assumed, contributed to opening the way for English colonization of America. Interest in the Orient at first proved greater, however, and, in 1600, London merchants formed an East India Company. It could not compete with the rival Dutch company in the region of largest profits—the East Indies—so it transferred its emphasis to the Indian subcontinent. The English acquired Masulipatam in 1611 and Madras in 1639, having meanwhile destroyed Portuguese Hormuz in 1622. Charles II obtained Bombay in 1661, as part of his Portuguese queen's marriage dowry, and awarded it to the company.

Collapse of the Mughal Empire after 1707 led ultimately to armed conflict between the British and French companies for increased trade and influence. Dupleix had won



the upper hand for France by 1748; but in the ensuing Seven Years' War (1756–63), fought between the major European powers in various parts of the world, the British company gained ascendancy in India, thanks largely to the ability of Robert Clive, and held it thereafter. Pondichéry surrendered; and, though France recovered this post by the ensuing Treaty of Paris (1763), French power in India had shrunk almost to nothing, while the British company's was now rivalled only by that of the native Marāthā confederacy.

Company profits from India came first from the familiar spices, but after 1660. Indian textiles outstripped these in importance. Cheap cloths, mainly cottons, found a mass market among the English poorer classes, though dainty fabrics for the wealthy also paid well. Imports of calicoes (inexpensive cotton fabrics from Calicut) to England grew so large that in 1721 Parliament passed the Calico Act to protect English manufacturers, forbidding the use of calico in England for apparel or for domestic purposes (repeal of the act in 1774 coincided with inventions of mechanical devices that made possible English cloth production in successful competition with Eastern fabrics).

England's American colonies. The English West Indies for many years exceeded North America in economic importance. The Lesser Antilles, earlier passed over by Spain in favour of the larger islands, lay open to any colonizer, though their ferocious Carib inhabitants sometimes gave trouble. The Leeward Islands of Antigua, St. Kitts, Nevis, and Barbados, as well as the Bermudas, were settled by Englishmen between 1609 and 1632. Barbados, at first the most important, owed its prosperity to the introduction of sugar culture about 1637. The size of landholdings increased in all the islands, and the white populations accordingly diminished as slavery came to furnish most of the raw labour. When an expedition sent by Oliver Cromwell took Spanish Jamaica in 1655, that island became the English West Indian centre. Settlement of Belize (later British Honduras) by buccaneers and log cutters began in 1636, although more than a century elapsed before Spain acknowledged that the English indeed had the right to be there.

Settlements in the West Indies

The English islanders, to the envy of their Dutch and French neighbours, enjoyed such constitutional privileges as the right to elect semipopular assemblies. Barbados once hoped to have two representatives in Parliament, and some Barbadians, during the English (Glorious) Revolution (1688–89), thought of making their island an independent state, but nothing came of this.

The original English mainland colonies—Virginia (founded 1607), Plymouth (1620), and Massachusetts Bay (1630)—were founded by joint-stock companies. The later New England settlements—New Hampshire, New Haven, Connecticut, and Rhode Island—began as offshoots of Massachusetts, which acquired jurisdiction over the Maine territory. The New England colonies were first peopled partly by religious dissenters, but except for the separatist Plymouth Pilgrims they did not formally secede from the Church of England for the time being.

Proprietary colonies, under individual entrepreneurs, began with Maryland, founded in 1634 under the Catholic direction of Cecilius and Leonard Calvert. Also proprietary was Pennsylvania, which originally included Delaware, founded by the Quaker William Penn in 1682. Maryland and Pennsylvania, except for a brief royal interlude in Maryland, continued under Calvert and Penn heirs until the American Revolution; all other colonies except Connecticut and Rhode Island ultimately had royal governments. The Carolinas, after abortive attempts at colonization, were effectively founded in 1670 and became first proprietary and, later, royal colonies. Georgia, last of the 13, began in 1732, partly as a philanthropic enterprise headed by James Oglethorpe to furnish a rehabilitation home for debtors and other underprivileged Englishmen. All the mainland colonies eventually had representative assemblies, chosen by the propertied classes, to aid and often handicap their English governors.

The original settlers, predominantly English, were later supplemented by French Huguenots, Germans, and Scots-Irish, especially in western New York, Pennsylvania, and the southern colonies. New York, acquired from the United Provinces of the Netherlands and including New Jersey, continued to have some Dutch flavour long after the Dutch had become a small minority. By the French and Indian War (1754–63, the American portion of the Seven Years' War), the total population of the mainland colonies was estimated as 1,296,000 whites and 300,000 blacks, enormously in excess of the 55,000 whites inhabiting French Canada.

The only bond of union among the British colonies was their allegiance to the king, and in the wars with France (*c.* 1689–1763) it proved hard to unite them against the common enemy. All the colonies were agricultural, with New England being a region of small farms, the Middle Atlantic colonies having a larger scaled and more diversified farming, and the southern ones tending to plantations on which tobacco, rice, and indigo were raised by slaves (although slavery was legal throughout all the colonies). There was much colonial shipping, especially from New England, whose merchants and seamen traded with England, Africa, and the West Indies; Massachusetts shipbuilders had built more than 700 ships by 1675. By 1763 several towns had grown into cities, including Boston, New York City, Philadelphia, Baltimore, and Charleston, South Carolina.

Economic activities in the English colonies

Mercantilism. By the time the term mercantile system was coined in 1776 by the Scottish philosopher Adam Smith, European states had been trying for two centuries to put mercantile theory into practice. The basis of mercantilism was the notion that national wealth is measured by the amount of gold and silver a nation possesses. This seemed proven by the fact that Spain's most powerful years had occurred when it was first reaping a bullion harvest from its overseas possessions.

The mercantile theory held that colonies exist for the economic benefit of the mother country and are useless unless they help to achieve profit. The mother nation should draw raw materials from its possessions and sell them finished goods, with the balance favouring the European country. This trade should be monopolistic, with foreign intruders barred.

The Spanish fleet system. Spain acted upon the as-yet-undefined mercantile theory when, in 1565, it perfected the fleet (*flota*) system, by which all legal trade with its American colonies was restricted to two annual fleets between Seville and designated ports on the Gulf of Mexico and Caribbean. The outgoing ships bore manufactured articles; returning, their cargoes consisted partly of gold and silver bars. Though the system continued for nearly two centuries, Spain was a poor country by 1700.

French mercantilist activities. Ignoring this lesson, other European states adopted the mercantilist policy; the France of Louis XIV and Colbert is the outstanding example. Colbert, who dominated French policy for 20 years, strictly regulated the economy. He instituted protective tariffs and sponsored a monopolistic merchant marine. He regarded what few overseas possessions France then had as ultimate sources of liquid wealth, which they were poorly situated to furnish because they lacked such supplies of bullion as Spain controlled in Mexico and Peru.

The English navigation acts. England adhered to mercantilism for two centuries and, possessing a more lucrative empire than France, strove to implement the policy by a series of navigation acts. The first, passed by Oliver Cromwell's government in 1651, attempted chiefly to exclude the Dutch from England's carrying trade: goods imported from Africa, Asia, or America could be brought only in English ships, which included colonial vessels, thus giving the English North American merchant marine a substantial stimulus. After the royal Restoration in 1660, Parliament renewed and strengthened the Cromwellian measures. By then colonial American maritime competition with England had grown so severe that laws of 1663 required colonial ships carrying European goods to America to route them through English ports, where a duty had to be paid, but from lack of enforcement these soon became inoperative. In the early 18th century the English lost some of their enthusiasm for bullion alone and placed

chief emphasis on commerce and industry. The Molasses Act of 1733 was in the interest of the British West Indian sugar growers, who complained of the amount of French island molasses imported by the mainland colonies; the French planters had been buying fish, livestock, and lumber brought by North American ships and gladly exchanging their sugar products for them at low prices. Prohibition of colonial purchases of French molasses, though decreed, went largely unenforced, and New England, home of most of the carrying trade, continued prosperous.

THE OLD COLONIAL SYSTEM AND THE COMPETITION FOR EMPIRE (18TH CENTURY)

Faith in mercantilism waned during the 18th century, first because of the influence of French Physiocrats, who advocated the rule of nature, whereby trade and industry would be left to follow a natural course. François Quesnay, a physician at the court of Louis XV of France, led this school of thought, fundamentally advocating an agricultural economy and holding that productive land was the only genuine wealth, with trade and industry existing for the transfer of agricultural products.

Publication of *Wealth of Nations*

Adam Smith adopted some physiocratic ideas, but he considered labour very important and did not altogether accept land as the sole wealth. Smith's *Inquiry Into the Nature and Causes of the Wealth of Nations* (1776), appearing just as Britain was about to lose much of its older empire, established the basis of new economic thought—classical economics. This denigrated mercantilism and advocated free, or at least freer, trade and state noninterference with private enterprise. *Laisser-faire et laisser-aller* ("to let it alone and let it flow") became the slogan of this British economic school. Smith thought that regulation only reduced wealth, a view in part adopted by the British government 56 years after his death.

Slave trade. Slavery, though abundantly practiced in Africa itself and widespread in the ancient Mediterranean world, had nearly died out in medieval Europe. It was revived by the Portuguese in Prince Henry's time, beginning with the enslavement of Berbers in 1442. Portugal populated Cape Verde, Fernando Po (now Bioko), and São Tomé largely with black slaves and took many to the home country, especially to the regions south of the Tagus River.

New World black slavery began in 1502, when Gov. Nicolás de Ovando of Hispaniola imported a few evidently Spanish-born blacks from Spain. Rapid decimation of the Indian population of the Spanish West Indies created a labour shortage, ultimately remedied from Africa. The great reformer, Las Casas, advocated importation of blacks to replace the vanishing Indians, and he lived to regret having done so. The population of the Greater Antilles became largely black and mulatto; on the mainland, at least in the more populated parts, the Indians, supplemented by a growing mestizo caste that clung more tenaciously to life and seemed more suited to labour, kept African slavery somewhat confined to limited areas.

The Portuguese at first practiced Indian slavery in Brazil and continued to employ it partially until 1755. It was gradually replaced by the African variety, beginning prominently in the 17th century and coinciding with the rapid rise of Brazilian sugar culture.

As the English, French, Dutch, and, to a lesser extent, the Danes colonized the smaller West Indian islands, these became plantation settlements, largely cultivated by blacks. Before the latter arrived in great numbers, the bulk of manual labour, especially in the English islands, was performed by poor whites. Some were indentured, or contract, servants; some were redemptioners who agreed to pay ship captains their passage fees within a stated time or be sold to bidders; others were convicts. Some were kidnapped, with the tacit approval of the English authorities, in keeping with the mercantilist policy that advocated getting rid of the unemployed and vagrants. Black slavery eventually surpassed white servitude in the West Indies.

John Hawkins commanded the first English slave-trading expedition in 1562 and sold his cargo in the Spanish Indies. English slaving, nevertheless, remained minor until the establishment of the English island colonies in the reign of James I (ruled 1603–25). A Dutch captain sailed the first cargo of black slaves to Virginia in 1619, the year in which the colony exported 20,000 pounds (9,000 kilograms) of tobacco. The restored Stuart king, Charles II, gave English slave trade to a monopolistic company, the Royal Adventurers Trading to Africa, in 1663, but the Adventurers accomplished little because of the early outbreak of war with Holland (1665). Its successor, the Royal African Company, was founded in 1672 and held the English monopoly until 1698, when all Englishmen received the right to trade in slaves. The Royal African Company continued slaving until 1731, when it abandoned slaving in favour of traffic in ivory and gold dust. A new slaving company, the Merchants Trading to Africa (founded 1750), had directors in London, Liverpool, and Bristol, with Bristol furnishing the largest quota of ships, estimated at 237 in 1755. Jamaica offered the greatest single market for slaves and is believed to have received 610,000 between 1700 and 1786. The slave trade still flourished in 1763, when about 150 ships sailed yearly from British ports to Africa with capacity for nearly 40,000 slaves.

First blacks in English North America

There was no well-organized opposition to the slave trade before 1800, although some individuals and ephemeral societies condemned it. The Spanish church saw the importation of blacks as an opportunity for converting them. The English religionist George Fox, founder of Quakerism (founded in the 1650s), accepted the fact that his followers had bought slaves in Barbados, but he urged kind treatment. The English novelist and political pamphleteer Daniel Defoe later denounced the traffic but seemingly regarded slavery itself as inevitable. The English and Pennsylvania Quakers passed resolutions forbidding their members to engage in the trade, but their wording suggests that some were doing so; in fact, 84 of them were members of the Merchants Trading to Africa.

Those opposing the slave trade often objected on other than humanitarian grounds. Some colonials feared any further growth of the black percentage of the population. Others, who justified English slave sales to the Spanish colonies because payment was in cash, condemned the same traffic with French islanders, who paid in molasses and thus competed with nearby English sugar planters.

Colonial wars of the 18th century. From 1689 to 1763 the British and French fought four wars that were mainly European in origin but which determined the colonial situation, in some cases for two centuries. Spain entered all four, first in alliance with England and later in partnership with France, though it played a secondary role.

King William's War (War of the League of Augsburg). The war known in Europe as that of the Palatinate, League of Augsburg, or Grand Alliance, and in America as King William's War, ended indecisively, after eight years, with the Treaty of Rijswijk in 1697. No territorial changes occurred in America, and because the great Mughal emperor Aurangzeb reigned in India, very little of the conflict penetrated there.

Queen Anne's War (War of the Spanish Succession). Queen Anne's War, the American phase of the War of the Spanish Succession (1701–14), began in 1702. Childless king Charles II of Spain, dying in 1700, willed his entire possessions to Philip, grandson of Louis XIV of France. England, the United Provinces, and Austria intervened, fearing a virtual union between powerful Louis and Spain detrimental to the balance of power, and Queen Anne's War lasted until terminated by the Treaty of Utrecht in 1713. England (Great Britain after 1707) gained Gibraltar and Minorca and, in North America, acquired Newfoundland and French Acadia (renamed Nova Scotia). It also received clear title to the northern area being exploited by the Hudson's Bay Company. Bourbon prince Philip was recognized as king of Spain, but the British secured the important *asiento,* or right to supply Spanish America with slaves, for 30 years.

British gains in North America

King George's War (War of the Austrian Succession). There followed a peace almost unbroken until 1739, when, with the *asiento* about to expire and Spain unwilling to renew it, Great Britain and Spain went to war. The recent amputation of an English seaman's ear by a Spanish Caribbean coast guard caused the conflict to be named

the War of Jenkins' Ear. This merged in 1740 with the War of the Austrian Succession (called King George's War in America), between Frederick II the Great of Prussia and Maria Theresa of Austria over Silesia. France joined Spain and Prussia against Great Britain and Austria, and the war, which was terminated in 1748 by the Treaty of Aix-la-Chapelle, proved indecisive. New England colonials captured Louisbourg, the fortified French island commanding the St. Lawrence entrance, but France's progress in India counterbalanced this conquest. With the Mughal Empire now virtually extinct, the British and French East India Companies fought each other, the advantage going to the French under Dupleix, who captured Madras and nearly expelled the British. The peace treaty restored all conquests; France recovered Louisbourg, and the British regained Madras and with it another chance to become paramount in India.

The French and Indian War (the Seven Years' War). Until 1754, when the two powers resumed their conflict in the French and Indian War in America, the overseas possessions maintained a show of peace. During this pre-war period the French attempted to increase their hold on the Ohio Valley and in 1754 built Fort-Duquesne at the future site of Pittsburgh. Lt. Col. George Washington with colonial forces, in 1754, and Gen. Edward Braddock with British regulars, in 1755, were defeated in attempts to dislodge them. Dupleix and his successor, Charles-Joseph Patissier, marquis de Bussy-Castelnau, increased their influence in India; but the recall of Dupleix in 1754 damaged French prospects there.

The Seven Years' War, fought in Europe by Frederick the Great of Prussia against Austria, France, and Russia, ended with his survival against overwhelming odds. His one ally, Great Britain, helped financially but could render small military assistance. Overseas, the British triumphed completely over France, aided by Spain in the last years of the war. The French at first had the upper hand in both India and America, but the turning point came after William Pitt the Elder, later earl of Chatham, assumed direction of the British war effort. In 1757 Clive won victory at Plassey over the Nawab of Bengal, an enemy of the British company; Sir Eyre Coote's victory at Wandewash in 1760, over the French governor Thomas Lally, was followed by the capture of Pondichéry.

Britain's overseas triumph over France

In America, thanks largely to the vigorous policy of Pitt, the British won repeated victories. The French forts Frontenac, Duquesne, and Carillon fell in 1758 and 1759. British generals Sir Jeffrey Amherst and James Wolfe took Louisbourg in 1758, Quebec in 1759, and Montreal in 1760, and the surrender of Montreal included that of the entire French colony. Meanwhile, Adm. Edward Hawke destroyed or immobilized the principal French line fleet at Quiberon Bay in 1759. Spanish intervention in the war in 1761 merely enabled the British to seize Havana and Manila.

The Treaty of Paris in 1763 gave Britain all North America east of the Mississippi, including Spanish Florida. France ceded the western Mississippi Valley to Spain as compensation for the loss of Florida. Besides having a clear path to domination of India in the Old World, Great Britain also gained African Senegal. In the West Indies, it returned Martinique and Guadeloupe to France for the sake of peace but remained easily second to Spain there in importance.

The first great era of colonial conflict had ended, and the British Empire, a century and a half old, had become the world's foremost overseas domain. Though exceeded in size by that of Spain, it was the wealthiest, backed by the overwhelming naval power of Great Britain. British prestige had reached a new height, greater perhaps than it would ever attain again.

(C.E.No./Ed.)

European expansion since 1763

Shift in colonial trade strategy

The global expansion of western Europe between the 1760s and the 1870s differed in several important ways from the expansionism and colonialism of previous centuries. Along with the rise of the Industrial Revolution, which economic historians generally trace to the 1760s, and the continuing spread of industrialization in the empire-building countries came a shift in the strategy of trade with the colonial world. Instead of being primarily buyers of colonial products (and frequently under strain to offer sufficient salable goods to balance the exchange), as in the past, the industrializing nations increasingly became sellers in search of markets for the growing volume of their machine-produced goods. Furthermore, over the years there occurred a decided shift in the composition of demand for goods produced in the colonial areas. Spices, sugar, and slaves became relatively less important with the advance of industrialization, concomitant with a rising demand for raw materials for industry (*e.g.*, cotton, wool, vegetable oils, jute, dyestuffs) and food for the swelling industrial areas (wheat, tea, coffee, cocoa, meat, butter).

This shift in trading patterns entailed in the long run changes in colonial policy and practice as well as in the nature of colonial acquisitions. The urgency to create markets and the incessant pressure for new materials and food were eventually reflected in colonial practices, which sought to adapt the colonial areas to the new priorities of the industrializing nations. Such adaptation involved major disruptions of existing social systems over wide areas of the globe. Before the impact of the Industrial Revolution, European activities in the rest of the world were largely confined to: (1) occupying areas that supplied precious metals, slaves, and tropical products then in large demand; (2) establishing white-settler colonies along the coast of North America; and (3) setting up trading posts and forts and applying superior military strength to achieve the transfer to European merchants of as much existing world trade as was feasible. However disruptive these changes may have been to the societies of Africa, South America, and the isolated plantation and white-settler colonies, the social systems over most of the Earth outside Europe nevertheless remained much the same as they had been for centuries (in some places for millennia). These societies, with their largely self-sufficient small communities based on subsistence agriculture and home industry, provided poor markets for the mass-produced goods flowing from the factories of the technologically advancing countries; nor were the existing social systems flexible enough to introduce and rapidly expand the commercial agriculture (and, later, mineral extraction) required to supply the food and raw material needs of the empire builders.

Adaptation of nonindustrialized regions

The adaptation of the nonindustrialized parts of the world to become more profitable adjuncts of the industrializing nations embraced, among other things: (1) overhaul of existing land and property arrangements, including the introduction of private property in land where it did not previously exist, as well as the expropriation of land for use by white settlers or for plantation agriculture; (2) creation of a labour supply for commercial agriculture and mining by means of direct forced labour and indirect measures aimed at generating a body of wage-seeking labourers; (3) spread of the use of money and exchange of commodities by imposing money payments for taxes and land rent and by inducing a decline of home industry; and (4) where the precolonial society already had a developed industry, curtailment of production and exports by native producers.

The classic illustration of this last policy is found in India. For centuries India had been an exporter of cotton goods, to such an extent that Great Britain for a long period imposed stiff tariff duties to protect its domestic manufacturers from Indian competition. Yet, by the middle of the 19th century, India was receiving one-fourth of all British exports of cotton piece goods and had lost its own export markets.

Clearly, such significant transformations could not get very far in the absence of appropriate political changes, such as the development of a sufficiently cooperative local elite, effective administrative techniques, and peace-keeping instruments that would assure social stability and environments conducive to the radical social changes imposed by a foreign power. Consistent with these purposes was the installation of new, or amendments of old, legal systems that would facilitate the operation of a money, business, and private land economy. Tying it all together

was the imposition of the culture and language of the dominant power.

The changing nature of the relations between centres of empire and their colonies, under the impact of the unfolding Industrial Revolution, was also reflected in new trends in colonial acquisitions. While in preceding centuries colonies, trading posts, and settlements were in the main, except for South America, located along the coastline or on smaller islands, the expansions of the late 18th century and especially of the 19th century were distinguished by the spread of the colonizing powers, or of their emigrants, into the interior of continents. Such continental extensions, in general, took one of two forms, or some combination of the two: (1) the removal of the indigenous peoples by killing them off or forcing them into specially reserved areas, thus providing room for settlers from western Europe who then developed the agriculture and industry of these lands under the social system imported from the mother countries, or (2) the conquest of the indigenous peoples and the transformation of their existing societies to suit the changing needs of the more powerful militarily and technically advanced nations.

New trends in colonial acquisitions

At the heart of Western expansionism was the growing disparity in technologies between those of the leading European nations and those of the rest of the world. Differences between the level of technology in Europe and some of the regions on other continents were not especially great in the early part of the 18th century. In fact, some of the crucial technical knowledge used in Europe at that time came originally from Asia. During the 18th century, however, and at an accelerating pace in the 19th and 20th centuries, the gap between the technologically advanced countries and technologically backward regions kept on increasing despite the diffusion of modern technology by the colonial powers. The most important aspect of this disparity was the technical superiority of Western armaments, for this superiority enabled the West to impose its will on the much larger colonial populations. Advances in communication and transportation, notably railroads, also became important tools for consolidating foreign rule over extensive territories. And along with the enormous technical superiority and the colonizing experience itself came important psychological instruments of minority rule by foreigners: racism and arrogance on the part of the colonizers and a resulting spirit of inferiority among the colonized.

Naturally, the above description and summary telescope events that transpired over many decades and the incidence of the changes varied from territory to territory and from time to time, influenced by the special conditions in each area, by what took place in the process of conquest, by the circumstances at the time when economic exploitation of the possessions became desirable and feasible, and by the varying political considerations of the several occupying powers. Moreover, it should be emphasized that expansion policies and practices, while far from haphazard, were rarely the result of long-range and integrated planning. The drive for expansion was persistent, as were the pressures to get the greatest advantage possible out of the resulting opportunities. But the expansions arose in the midst of intense rivalry among major powers that were concerned with the distribution of power on the continent of Europe itself as well as with ownership of overseas territories. Thus, the issues of national power, national wealth, and military strength shifted more and more to the world stage as commerce and territorial acquisitions spread over larger segments of the globe. In fact, colonies were themselves often levers of military power—sources of military supplies and of military manpower and bases for navies and merchant marines. What appears, then, in tracing the concrete course of empire is an intertwining of the struggle for hegemony between competing national powers, the manoeuvring for preponderance of military strength, and the search for greatest advantage practically obtainable from the world's resources.

Influences behind expansion policies

EUROPEAN COLONIAL ACTIVITY (1763–C. 1875)

Stages of history rarely, if ever, come in neat packages: the roots of new historical periods begin to form in earlier eras, while many aspects of an older phase linger on and help shape the new. Nonetheless, there was a convergence of developments in the early 1760s, which, despite many qualifications, delineates a new stage in European expansionism and especially in that of the most successful empire builder, Great Britain. It is not only the Industrial Revolution in Great Britain that can be traced to this period but also the consequences of England's decisive victory over France in the Seven Years' War and the beginnings of what turned out to be the second British Empire. As a result of the Treaty of Paris, France lost nearly all of its colonial empire, while Britain became, except for Spain, the largest colonial power in the world.

The second British Empire. The removal of threat from the strongest competing foreign power set the stage for Britain's conquest of India and for operations against the North American Indians to extend British settlement in Canada and westerly areas of the North American continent. In addition, the new commanding position on the seas provided an opportunity for Great Britain to probe for additional markets in Asia and Africa and to try to break the Spanish trade monopoly in South America. During this period, the scope of British world interests broadened dramatically to cover the South Pacific, the Far East, the South Atlantic, and the coast of Africa.

British naval superiority

The initial aim of this outburst of maritime activity was not so much the acquisition of extensive fresh territory as the attainment of a far-flung network of trading posts and maritime bases. The latter, it was hoped, would serve the interdependent aims of widening foreign commerce and controlling ocean shipping routes. But in the long run many of these initial bases turned out to be steppingstones to future territorial conquests. Because the indigenous populations did not always take kindly to foreign incursions into their homelands, even when the foreigners limited themselves to small enclaves, penetration of interiors was often necessary to secure base areas against attack.

Loss of the American colonies. The path of conquest and territorial growth was far from orderly. It was frequently diverted by the renewal or intensification of rivalry between, notably, England, France, Spain, and the Low Countries in colonial areas and on the European continent. The most severe blow to Great Britain's 18th-century dreams of empire, however, came from the revolt of the 13 American colonies. These contiguous colonies were at the heart of the old, or what is often referred to as the first, British Empire, which consisted primarily of Ireland, the North American colonies, and the plantation colonies of the West Indies. Ironically, the elimination of this core of the first British Empire was to a large extent influenced by the upsurge of empire building after the Seven Years' War. Great Britain harvested from its victory in that war a new expanse of territory about equal to its prewar possessions on the North American continent: French Canada, the Floridas, and the territory between the Alleghenies and the Mississippi River. The assimilation of the French Canadians, control of the Indians and settlement of the trans-Allegheny region, and the opening of new trade channels created a host of problems for the British government. Not the least of these were the burdensome costs to carry out this program on top of a huge national debt accumulated during the war. To cope with these problems, new imperial policies were adopted by the mother country: raising (for the first time) revenue from the colonies; tightening mercantile restrictions, imposing firm measures against smuggling (an important source of income for colonial merchants), and putting obstacles in the way of New England's substantial trade with the West Indies. The strains generated by these policies created or intensified the hardships of large sections of the colonial population and, in addition, disrupted the relative harmony of interests that had been built up between the mother country and important elite groups in the colonies. Two additional factors, not unrelated to the enlargement of the British Empire, fed the onset and success of the American War of Independence (1775–83): first, a lessening need for military support from the mother country once the menacing French were removed from the continent and, second, support for the American

Imperial policies in the late 18th century

Revolutionary forces from the French and Spanish, who had much to fear from the enhanced sea power and expansionism of the British.

The shock of defeat in North America was not the only problem confronting British society. Ireland—in effect, a colonial dependency—also experienced a revolutionary upsurge, giving added significance to attacks by leading British free traders against existing colonial policies and even at times against colonialism itself. But such criticism had little effect except as it may have hastened colonial administrative reforms to counteract real and potential independence movements in dependencies such as Canada and Ireland.

Conquest of India. Apart from reforms of this nature, the aftermath of American independence was a diversion of British imperial interests to other areas—the beginning of the settlement of Australia being a case in point. In terms of amount of effort and significance of results, however, the pursuit of conquest in India took first place. Starting with the assumption of control over the province of Bengal (after the Battle of Plassey, 1757) and especially after the virtual removal of French influence from the Indian Ocean, the British waged more or less continuous warfare against the Indian people and took over more and more of the interior. The Marāthās, the main source of resistance to foreign intrusion, were decisively defeated in 1803, but military resistance of one sort or another continued until the middle of the 19th century. The financing and even the military manpower for this prolonged undertaking came mainly from India itself. As British sovereignty spread, new land-revenue devices were soon instituted, which resulted in raising the revenue to finance the consolidation of power in India and the conquest of other regions, breaking up the old system of self-sufficient and self-perpetuating villages and supporting an elite whose self-interests would harmonize with British rule.

Defeat of the Marāthās

Global expansion. Except for the acquisition of additional territory in India and colonies in Sierra Leone and New South Wales, the important additions to British overseas possessions between the Seven Years' War and the end of the Napoleonic era came as prizes of victory in wars with rival European colonial powers. In 1763 the first British Empire primarily centred on North America. By 1815, despite the loss of the 13 colonies, Britain had a second empire, one that straddled the globe from Canada and the Caribbean in the Western Hemisphere around the Cape of Good Hope to India and Australia. This empire was sustained by and in turn was supported by maritime power that far exceeded that of any of Britain's European rivals.

Policy changes. The half century of global expansion is only one aspect of the transition to the second British Empire. The operations of the new empire in the longer run also reflected decisive changes in British society. The replacement of mercantile by industrial enterprise as the main source of national wealth entailed changes to make national and colonial policy more consistent with the new hierarchy of interests. The restrictive trade practices and monopolistic privileges that sustained the commercial explosion of the 16th and most of the 17th centuries—built around the slave trade, colonial plantations, and monopolistic trading companies—did not provide the most effective environment for a nation on its way to becoming the workshop of the world.

The desired restructuring of policies occurred over decades of intense political conflict: the issues were not always clearly delineated, interest groups frequently overlapped, and the balance of power between competing vested interests shifted from time to time. The issues were clearly drawn in some cases, as for example over the continuation of the British East India Company's trade monopoly. The company's export of Indian silk, muslins, and other cotton goods was seen by all who were involved in any way in the production of British textiles to be an obstacle to the development of markets for competing British manufactures. Political opposition to this monopoly was strong at the end of the 18th century, but the giant step on the road to free trade was not taken until the early decades of the 19th century (termination of the Indian trade monopoly, 1813; of the Chinese trade monopoly, 1833).

In contrast, the issues surrounding the strategic slave trade were much more complicated. The West Indies plantations relied on a steady flow of slaves from Africa. British merchants and ships profited not only from supplying these slaves but also from the slave trade with other colonies in the Western Hemisphere. The British were the leading slave traders, controlling at least half of the transatlantic slave trade by the end of the 18th century. But the influential planter and slave-trade interests had come under vigorous and unrelenting attack by religious and humanitarian leaders and organizations, who propelled the issue of abolition to the forefront of British politics around the turn of the 19th century. Historians are still unravelling the threads of conflicting arguments about the priority of causes in the final abolition of the slave trade and, later, of slavery itself, because economic as well as political issues were at play: glutted sugar markets (to which low-cost producers in competing colonies contributed) stimulated thoughts about controlling future output by limiting the supply of fresh slaves; the compensation paid to plantation owners by the British government at the time of the abolition of slavery rescued many planters from bankruptcy during a sugar crisis, with a substantial part of the compensation money being used to pay off planters' debts to London bankers. Moreover, the battle between proslavery and antislavery forces was fought in an environment in which free-trade interests were challenging established mercantilist practices and the West Indies sugar economy was in a secular decline.

Controversy over the slave trade

The British were not the first to abolish the slave trade. Denmark had ended it earlier, and the U.S. Constitution, written in 1787, had already provided for its termination in 1808. But the British Act of 1807 formally forbidding the slave trade was followed up by diplomatic and naval pressure to suppress the trade. By the 1820s Holland, Sweden, and France had also passed anti-slave-trade laws. Such laws and attempts to enforce them by no means stopped the trade, so lòng as there was buoyant demand for this commodity and good profit from dealing in it. Some decline in the demand for slaves did follow the final emancipation in 1833 of slaves in British possessions. On the other hand, the demand for slaves elsewhere in the Americas took on new life—*e.g.*, to work the virgin soils of Cuba and Brazil and to pick the rapidly expanding U.S. cotton crops to feed the voracious appetite of the British textile industry. Accordingly, the number of slaves shipped across the Atlantic accelerated at the same time Britain and other maritime powers outlawed this form of commerce.

Involvement in Africa. Although Britain's energetic activity to suppress the slave trade was far from effective, its diplomatic and military operations for this end led it to much greater involvement in African affairs. Additional colonies were acquired (Sierra Leone, 1808; Gambia, 1816; Gold Coast, 1821) to serve as bases for suppressing the slave trade and for stimulating substitute commerce. British naval squadrons touring the coast of Africa, stopping and inspecting suspected slavers of other nations, and forcing African tribal chiefs to sign antislavery treaties did not halt the expansion of the slave trade, but they did help Britain attain a commanding position along the west coast of Africa, which in turn contributed to the expansion of both its commercial and colonial empire.

The growth of informal empire. The transformation of the old colonial and mercantilist commercial system was completed when, in addition to the abolition of slavery and the slave trade, the Corn Laws and the Navigation Acts were repealed in the late 1840s. The repeal of the Navigation Acts acknowledged the new reality: the primacy of Britain's navy and merchant shipping. The repeal of the Corn Laws (which had protected agricultural interests) signalled the maturation of the Industrial Revolution. In the light of Britain's manufacturing supremacy, exclusivity and monopolistic trade restraints were less important than, and often detrimental to, the need for ever-expanding world markets and sources of inexpensive raw materials and food.

Repeal of the Navigation Acts and Corn Laws

With the new trade strategy, under the impetus of freer trade and technical progress, came a broadening of the concept of empire. It was found that the commercial and financial advantages of formal empire could often be derived by informal means. The development of a worldwide trade network, the growth of overseas banking, the export of capital to less advanced regions, the leading position of London's money markets—all under the shield of a powerful and mobile navy—led to Great Britain's economic preeminence and influence in many parts of the world, even in the absence of political control.

Anticolonial sentiment. The growing importance of informal empire went hand in hand with increased expressions of dissatisfaction with the formal colonial empire. The critical approach to empire came from leading statesmen, government officials in charge of colonial policy, the free traders, and the philosophic Radicals (the latter, a broad spectrum of opinion makers often labelled the Little Englanders, whose voices of dissent were most prominent in the years between 1840 and 1870). Taking the long view, however, some historians question just how much of this current of political thought was really concerned with the transformation of the British Empire into a Little England. Those who seriously considered colonial separation were for the most part thinking of the more recent white-settler colonies, such as Canada, Australia, and New Zealand, and definitely not of independence for India nor, for that matter, for Ireland. Differences of opinion among the various political factions naturally existed over the best use of limited government finance, colonial administrative tactics, how much foreign territory could in practice be controlled, and such issues as the costs of friction with the United States over Canada. Yet, while there were important differences of opinion on the choice between formal and informal empire, no important conflict arose over the desirability of continued expansion of Britain's world influence and foreign commercial activity. Indeed, during the most active period of what has been presumed to be anticolonialism, both the formal and informal empires grew substantially: new colonies were added, the territory of existing colonies was enlarged, and military campaigns were conducted to widen Britain's trading and investment area, as in the Opium Wars of the mid-19th century.

Continued imperial growth

Decline of colonial rivalry. An outstanding development in colonial and empire affairs during the period between the Napoleonic Wars and the 1870s was an evident lessening in conflict between European powers. Not that conflict disappeared entirely, but the period as a whole was one of relative calm compared with either the almost continuous wars for colonial possessions in the 18th century or the revival of intense rivalries during the latter part of the 19th and early 20th centuries. Instead of wars among colonial powers during this period, there were wars against colonized peoples and their societies, incident either to initial conquest or to the extension of territorial possessions farther into the interior. Examples are Great Britain in India, Burma, South Africa (Kaffir Wars), New Zealand (Maori Wars); France in Algeria and Indochina; the Low Countries in Indonesia; Russia in Central Asia; and the United States against the North American Indians.

Contributing to the abatement of intercolonial rivalries was the undisputable supremacy of the British Navy during these years. The increased use of steamships in the 19th century helped reinforce this supremacy: Great Britain's ample domestic coal supply and its numerous bases around the globe (already owned or newly obtained for this purpose) combined to make available needed coaling stations. Over several decades of the 19th century and until new developments toward the end of the century opened up a new age of naval rivalry, no country was in a position to challenge Britain's dominance of the seas. This may have temporarily weakened Britain's acquisitive drive: the motive of preclusive occupation of foreign territory still occurred, but it was not as pressing as at other times.

On the whole, despite the relative tranquillity and the rise of anticolonial sentiment in Britain, the era was marked by a notable wave of European expansionism: Thus, in 1800 Europe and its possessions, including former colonies, claimed title to about 55 percent of the Earth's land surface: Europe, North and South America, most of India, the Russian part of Asia, parts of the East Indies, and small sections along the coast of Africa. But much of this was merely claimed; effective control existed over a little less than 35 percent, most of which consisted of Europe itself. By 1878—that is, before the next major wave of European acquisitions began—an additional 6,500,000 square miles (16,800,000 square kilometres) were claimed; during this period, control was consolidated over the new claims and over all the territory claimed in 1800. Hence, from 1800 to 1878, actual European rule (including former colonies in North and South America) increased from 35 to 67 percent of the Earth's land surface.

Consolidation of European colonial rule

Decline of the Spanish and Portuguese empires. During the early 19th century, however, there was a conspicuous exception to the trend of colonial growth, and that was the decline of the Portuguese and Spanish empires in the Western Hemisphere. The occasion for the decolonization was provided by the Napoleonic Wars. The French occupation of the Iberian Peninsula in 1807, combined with the ensuing years of intense warfare until 1814 on that peninsula between the British and French and their respective allies, effectively isolated the colonies from their mother countries. During this isolation the long-smouldering discontents in the colonies erupted in influential nationalist movements, revolutions of independence, and civil wars. The stricken mother countries could hardly interfere with events on the South American continent, nor did they have the resources, even after the Peninsular War was over, to bring enough soldiers and armaments across the Atlantic to suppress the independence forces.

Great Britain could have intervened on behalf of Spain and Portugal, but it declined. British commerce with South America had blossomed during the Napoleonic Wars. New vistas of potentially profitable opportunities opened up in those years, in contrast with preceding decades when British penetration of Spanish colonial markets consisted largely of smuggling to get past Spain's mercantile restrictions. The British therefore now favoured independence for these colonies and had little interest in helping to reimpose colonial rule, with its accompanying limitations on British trade and investment. Support for colonial independence by the British came in several ways: merchants and financiers provided loans and supplies needed by insurrectionary governments; the Royal Navy protected the shipment of those supplies and the returning specie; and the British government made it clear to other nations that it considered South American countries independent. The British forthright position on independence, as well as the availability of the Royal Navy to support this policy, gave substance to the U.S. Monroe Doctrine (1823), which the United States had insufficient strength at that time to really enforce.

After some 15 years of uprisings and wars, Spain by 1825 no longer had any colonies in South America itself, retaining only the islands of Cuba and Puerto Rico. During the same period Brazil achieved its independence from Portugal. The advantages to the British economy made possible by the consequent opening up of the Latin-American ports were eagerly pursued, facilitated by commercial treaties signed with these young nations. The reluctance of France to recognize their new status delayed French penetration of their markets and gave an advantage to the British. In one liberated area after another, brokers and commercial agents arrived from England to ferret out business opportunities. Soon the continent was flooded with British goods, often competing with much weaker native industries. Actually, Latin America provided the largest single export market for British cotton textiles in the first half of the 19th century.

South American independence

Despite the absence of formal empire, the British were able to attain economic preeminence in South America. Spanish and Portuguese colonialism had left a heritage of disunity and conflict within regions of new nations and between nations, along with conditions that led to unstable alliances of ruling elite groups. While this combination of weaknesses militated against successful self-development,

it was fertile ground for energetic foreign entrepreneurs, especially those who had technically advanced manufacturing capacities, capital resources, international money markets, insurance and shipping facilities, plus supportive foreign policies. The early orgy of speculative loans and investments soon ended. But before long, British economic penetration entered into more lasting and self-perpetuating activities, such as promoting Latin-American exports, providing railroad equipment, constructing public works, and supplying banking networks. Thus, while the collapse of the Spanish and Portuguese empires led to the decline of colonialism in the Western Hemisphere, it also paved the way for a significant expansion of Britain's informal empire of trade, investment, and finance during the 19th century.

The emigration of European peoples. European influence around the globe increased with each new wave of emigration from Europe. Tides of settlers brought with them the Old World culture and, often, useful agricultural and industrial skills. An estimated 55,000,000 Europeans left their native lands in the 100 years after 1820, the product chiefly of two forces: (1) the push to emigrate as a result of difficulties arising from economic dislocations at home and (2) the pull of land, jobs, and recruitment activities of passenger shipping lines and agents of labour-hungry entrepreneurs in the New World. Other factors were also clearly at work, such as the search for religious freedom, escape from tyrannical governments, avoidance of military conscription, and the desire for greater upward social and economic mobility. Such motives had existed throughout the centuries, however, and they are insufficient to explain the massive population movements that characterized the 19th century. Unemployment induced by rapid technological changes in agriculture and industry was an important incentive for English emigration in the mid-1800s. The surge of German emigration at roughly the same time is largely attributable to an agricultural revolution in Germany, which nearly ruined many farmers on small holdings in southwestern Germany. Under English rule, the Irish were prevented from industrial development and were directed to an economy based on export of cereals grown on small holdings. A potato blight, followed by famine and eviction of farm tenants by landlords, gave large numbers of Irish no alternative other than emigration or starvation. These three nationalities—English, German, and Irish—composed the largest group of migrants in the 1850s. In later years Italians and Slavs contributed substantially to the population spillover. The emigrants spread throughout the world, but the bulk of the population transfer went to the Americas, Siberia, and Australasia. The population outflow, greatly facilitated by European supremacy outside Europe, helped ease the social pressures and probably abated the dangers of social upheaval in Europe itself.

Spread of European culture and technology

Advance of the U.S. frontier. The outward movement of European peoples in any substantial numbers naturally was tied in with conquest and, to a greater or lesser degree, with the displacement of indigenous populations. In the United States, where by far the largest number of European emigrants went, acquisition of space for development by white immigrants entailed activity on two fronts: competition with rival European nations and disposition of the Indians. During a large part of the 19th century, the United States remained alert to the danger of encirclement by Europeans, but in addition the search for more fertile land, pursuit of the fur trade, and desire for ports to serve commerce in the Atlantic and Pacific oceans nourished the drive to penetrate the American continent. The most pressing points of tension with European nations were eliminated during the first half of the century: purchase of the Louisiana Territory from France in 1803 gave the United States control over the heartland of the continent; settlement of the War of 1812 ended British claims south of the 49th parallel up to the Rocky Mountains; Spain's cession of the Floridas in 1819 rounded out the Atlantic coastal frontier; and Russia's (1824) and Great Britain's (1846) relinquishment of claims to the Oregon territory gave the United States its window on the Pacific. The expansion of the United States, however, was not confined to liquidating rival claims of overseas empires; it also involved taking territory from neighbouring Mexico. Settlers from the United States wrested Texas from Mexico (1836), and war against Mexico (1846–48) led to the U.S. annexation of the southwestern region between New Mexico and Utah to the Pacific Ocean.

Penetration of the American continent

Diplomatic and military victories over the European nations and Mexico were but one precondition for the transcontinental expansion of the United States. In addition, the Indian tribes sooner or later had to be rooted out to clear the new territory. At times, treaties were arranged with Indian tribes, by which vast areas were opened up for white settlement. But even where peaceful agreements had been reached, the persistent pressure of the search for land and commerce created recurrent wars with Indian tribes that were seeking to retain their homes and their land. Room for the new settlers was obtained by forced removal of natives to as yet non-white-settled land—a process that was repeated as white settlers occupied ever more territory. Massacres during wars, susceptibility to infectious European diseases, and hardships endured during forced migrations all contributed to the decline in the Indian population and the weakening of its resistance. Nevertheless, Indian wars occupied the U.S. Army's attention during most of the 19th century, ending with the eventual isolation of the surviving Indians on reservations set aside by the U.S. government.

THE NEW IMPERIALISM (C. 1875–1914)

Reemergence of colonial rivalries. Although there are sharp differences of opinion over the reasons for, and the significance of, the "new imperialism," there is little dispute that at least two developments in the late 19th and in the beginning of the 20th century signify a new departure: (1) notable speedup in colonial acquisitions; (2) an increase in the number of colonial powers.

New acquisitions. The annexations during this new phase of imperial growth differed significantly from the expansionism earlier in the 19th century. While the latter was substantial in magnitude, it was primarily devoted to the consolidation of claimed territory (by penetration of continental interiors and more effective rule over indigenous populations) and only secondarily to new acquisitions. On the other hand, the new imperialism was characterized by a burst of activity in carving up as yet independent areas: taking over almost all Africa, a good part of Asia, and many Pacific islands. This new vigour in the pursuit of colonies is reflected in the fact that the rate of new territorial acquisitions of the new imperialism was almost three times that of the earlier period. Thus, the increase in new territories claimed in the first 75 years of the 19th century averaged about 83,000 square miles (215,000 square kilometres) a year. As against this, the colonial powers added an average of about 240,000 square miles (620,000 square kilometres) a year between the late 1870s and World War I (1914–18). By the beginning of that war, the new territory claimed was for the most part fully conquered, and the main military resistance of the indigenous populations had been suppressed. Hence, in 1914, as a consequence of this new expansion and conquest on top of that of preceding centuries, the colonial powers, their colonies, and their former colonies extended over approximately 85 percent of the Earth's surface. Economic and political control by leading powers reached almost the entire globe, for, in addition to colonial rule, other means of domination were exercised in the form of spheres of influence, special commercial treaties, and the subordination that lenders often impose on debtor nations.

Increase in new territories in Africa and Asia

New colonial powers. This intensification of the drive for colonies reflected much more than a new wave of overseas activities by traditional colonial powers, including Russia. The new imperialism was distinguished particularly by the emergence of additional nations seeking slices of the colonial pie: Germany, the United States, Belgium, Italy, and, for the first time, an Asian power, Japan. Indeed, this very multiplication of colonial powers, occurring in a relatively short period, accelerated the tempo of colonial growth. Unoccupied space that could

potentially be colonized was limited. Therefore, the more nations there were seeking additional colonies at about the same time, the greater was the premium on speed. Thus, the rivalry among the colonizing nations reached new heights, which in turn strengthened the motivation for preclusive occupation of territory and for attempts to control territory useful for the military defense of existing empires against rivals.

The impact of the new upsurge of rivalry is well illustrated in the case of Great Britain. Relying on its economic preeminence in manufacturing, trade, and international finance as well as on its undisputed mastery of the seas during most of the 19th century, Great Britain could afford to relax in the search for new colonies, while concentrating on consolidation of the empire in hand and on building up an informal empire. But the challenge of new empire builders, backed up by increasing naval power, put a new priority on Britain's desire to extend its colonial empire. On the other hand, the more that potential colonial space shrank, the greater became the urge of lesser powers to remedy disparities in size of empires by redivision of the colonial world. The struggle over contested space and for redivision of empire generated an increase in wars among the colonial powers and an intensification of diplomatic manoeuvring.

Struggle over redivision of empire

Rise of new industrialized nations. Parallel with the emergence of new powers seeking a place in the colonial sun and the increasing rivalry among existing colonial powers was the rise of industrialized nations able and willing to challenge Great Britain's lead in industry, finance, and world trade. In the mid-19th century Britain's economy outdistanced by far its potential rivals. But, by the last quarter of that century, Britain was confronted by restless competitors seeking a greater share of world trade and finance; the Industrial Revolution had gained a strong foothold in these nations, which were spurred on to increasing industrialization with the spread of railroad lines and the maturation of integrated national markets.

Moreover, the major technological innovations of the late 19th and early 20th centuries improved the competitive potential of the newer industrial nations. Great Britain's advantage as the progenitor of the first Industrial Revolution diminished substantially as the newer products and sources of energy of what has been called a second Industrial Revolution began to dominate industrial activity. The late starters, having digested the first Industrial Revolution, now had a more equal footing with Great Britain: they were all starting out more or less from the same base to exploit the second Industrial Revolution. This new industrialism, notably featuring mass-produced steel, electric power and oil as sources of energy, industrial chemistry, and the internal-combustion engine, spread over western Europe, the United States, and eventually Japan.

Need for heavy capital investment

A world economy. To operate efficiently, the new industries required heavy capital investment in large-scale units. Accordingly, they encouraged the development of capital markets and banking institutions that were large and flexible enough to finance the new enterprises. The larger capital markets and industrial enterprises, in turn, helped push forward the geographic scale of operations of the industrialized nations: more capital could now be mobilized for foreign loans and investment, and the bigger businesses had the resources for the worldwide search for and development of the raw materials essential to the success and security of their investments. Not only did the new industrialism generate a voracious appetite for raw materials, but food for the swelling urban populations was now also sought in the far corners of the world. Advances in ship construction (steamships using steel hulls, twin screws, and compound engines) made feasible the inexpensive movement of bulk raw materials and food over long ocean distances. Under the pressures and opportunities of the later decades of the 19th century, more and more of the world was drawn upon as primary producers for the industrialized nations. Self-contained economic regions dissolved into a world economy, involving an international division of labour whereby the leading industrial nations made and sold manufactured products and the rest of the world supplied them with raw materials and food.

New militarism. The complex of social, political, and economic changes that accompanied the new industrialism and the vastly expanded and integrated world commerce also provided a setting for intensified commercial rivalry, the rebuilding of high tariff walls, and a revival of militarism. Of special importance militarily was the race in naval construction, which was propelled by the successful introduction and steady improvement of radically new warships that were steam driven, armour-plated, and equipped with weapons able to penetrate the new armour. Before the development of these new technologies, Britain's naval superiority was overwhelming and unchallengeable. But because Britain was now obliged in effect to build a completely new navy, other nations with adequate industrial capacities and the will to devote their resources to this purpose could challenge Britain's supremacy at sea.

The new militarism and the intensification of colonial rivalry signalled the end of the relatively peaceful conditions of the mid-19th century. The conflict over the partition of Africa, the South African War (the Boer War), the Sino-Japanese War, the Spanish-American War, and the Russo-Japanese War were among the indications that the new imperialism had opened a new era that was anything but peaceful.

The new imperialism also represented an intensification of tendencies that had originated in earlier periods. Thus, for example, the decision by the United States to go to war with Spain cannot be isolated from the long-standing interest of the United States in the Caribbean and the Pacific. The defeat of Spain and the suppression of the independence revolutions in Cuba and the Philippines gave substance to the Monroe Doctrine: the United States now became the dominant power in the Caribbean, and the door was opened for acquisition of greater influence in Latin America. Possession of the Philippines was consistent with the historic interest of the United States in the commerce of the Pacific, as it had already manifested by its long interest in Hawaii (annexed in 1898) and by an expedition by Commodore Matthew Perry to Japan (1853).

Historiographical debate. The new imperialism marked the end of vacillation over the choice of imperialist military and political policies; similar decisions to push imperialist programs to the forefront were made by the leading industrial nations over a relatively short period. This historical conjuncture requires explanation and still remains the subject of debate among historians and social scientists. The pivot of the controversy is the degree to which the new imperialism was the product of primarily economic forces and in particular whether it was a necessary attribute of the capitalist system.

Serious analysts on both sides of the argument recognize that there is a multitude of factors involved: the main protagonists of economic imperialism recognize that political, military, and ideological influences were also at work; similarly, many who dispute the economic imperialism thesis acknowledge that economic interests played a significant role. The problem, however, is one of assigning priority to causes.

Hobson's interpretation of the new imperialism

Economic imperialism. The father of the economic interpretation of the new imperialism was the British liberal economist John Atkinson Hobson. In his seminal study, *Imperialism, a Study* (first published in 1902), he pointed to the role of such drives as patriotism, philanthropy, and the spirit of adventure in advancing the imperialist cause. As he saw it, however, the critical question was why the energy of these active agents takes the particular form of imperialist expansion. Hobson located the answer in the financial interests of the capitalist class as "the governor of the imperial engine." Imperialist policy had to be considered irrational if viewed from the vantage point of the nation as a whole: the economic benefits derived were far less than the costs of wars and armaments; and needed social reforms were shunted aside in the excitement of imperial adventure. But it was rational, indeed, in the eyes of the minority of financial interest groups. The reason for this, in Hobson's view, was the persistent congestion of capital in manufacturing. The pressure of capital needing investment outlets arose in part from a maldistribution of

income: low mass consuming power blocks the absorption of goods and capital inside the country. Moreover, the practices of the larger firms, especially those operating in trusts and combines, foster restrictions on output, thus avoiding the risks and waste of overproduction. Because of this, the large firms are faced with limited opportunities to invest in expanding domestic production. The result of both the maldistribution of income and monopolistic behaviour is a need to open up new markets and new investment opportunities in foreign countries.

Hobson's study covered a broader spectrum than the analysis of what he called its economic taproot. It also examined the associated features of the new imperialism, such as political changes, racial attitudes, and nationalism. The book as a whole made a strong impression on, and greatly influenced, Marxist thinkers who were becoming more involved with the struggle against imperialism. The most influential of the Marxist studies was a small book published by Lenin in 1917, *Imperialism, the Highest Stage of Capitalism.* Despite many similarities, at bottom there is a wide gulf between Hobson's and Lenin's frameworks of analysis and also between their respective conclusions. While Hobson saw the new imperialism serving the interests of certain capitalist groups, he believed that imperialism could be eliminated by social reforms while maintaining the capitalist system. This would require restricting the profits of those classes whose interests were closely tied to imperialism and attaining a more equitable distribution of income so that consumers would be able to buy up a nation's production. Lenin, on the other hand, saw imperialism as being so closely integrated with the structure and normal functioning of an advanced capitalism that he believed that only the revolutionary overthrow of capitalism, with the substitution of Socialism, would rid the world of imperialism.

Marxist interpretation

Lenin placed the issues of imperialism in a context broader than the interests of a special sector of the capitalist class. According to Lenin, capitalism itself changed in the late 19th century; moreover, because this happened at pretty much the same time in several leading capitalist nations, it explains why the new phase of capitalist development came when it did. This new phase, Lenin believed, involves political and social as well as economic changes; but its economic essence is the replacement of competitive capitalism by monopoly capitalism, a more advanced stage in which finance capital, an alliance between large industrial and banking firms, dominates the economic and political life of society. Competition continues, but among a relatively small number of giants who are able to control large sectors of the national and international economy. It is this monopoly capitalism and the resulting rivalry generated among monopoly capitalist nations that foster imperialism; in turn, the processes of imperialism stimulate the further development of monopoly capital and its influence over the whole society.

The difference between Lenin's more complex paradigm and Hobson's shows up clearly in the treatment of capital export. Like Hobson, Lenin maintained that the increasing importance of capital exports is a key figure of imperialism, but he attributed the phenomenon to much more than pressure from an overabundance of capital. He also saw the acceleration of capital migration arising from the desire to obtain exclusive control over raw material sources and to get a tighter grip on foreign markets. He thus shifted the emphasis from the general problem of surplus capital, inherent in capitalism in all its stages, to the imperatives of control over raw materials and markets in the monopoly stage. With this perspective, Lenin also broadened the concept of imperialism. Because the thrust is to divide the world among monopoly interest groups, the ensuing rivalry extends to a struggle over markets in the leading capitalist nations as well as in the less advanced capitalist and colonial countries. This rivalry is intensified because of the uneven development of different capitalist nations: the latecomers aggressively seek a share of the markets and colonies controlled by those who got there first, who naturally resist such a redivision. Other forces—political, military, and ideological—are at play in shaping the contours of imperialist policy, but Lenin insisted that these influences germinate in the seedbed of monopoly capitalism.

Noneconomic imperialism. Perhaps the most systematic alternative theory of imperialism was proposed by Joseph Alois Schumpeter, one of the best known economists of the first half of the 20th century. His essay "Zur Soziologie des Imperialismus" ("The Sociology of Imperialism") was first published in Germany in the form of two articles in 1919. Although Schumpeter was probably not familiar with Lenin's *Imperialism* at the time he wrote his essay, his arguments were directed against the Marxist currents of thought of the early 20th century and in particular against the idea that imperialism grows naturally out of capitalism. Unlike other critics, however, Schumpeter accepted some of the components of the Marxist thesis, and to a certain extent he followed the Marxist tradition of looking for the influence of class forces and class interests as major levers of social change. In doing so, he in effect used the weapons of Marxist thought to rebut the essence of Marxist theory.

Schumpeter's interpretation

A survey of empires, beginning with the earliest days of written history, led Schumpeter to conclude that there are three generic characteristics of imperialism: (1) At root is a persistent tendency to war and conquest, often producing nonrational expansions that have no sound utilitarian aim. (2) These urges are not innate in man. They evolved from critical experiences when peoples and classes were molded into warriors to avoid extinction; the warrior mentality and the interests of warrior classes live on, however, and influence events even after the vital need for wars and conquests disappears. (3) The drift to war and conquest is sustained and conditioned by the domestic interests of ruling classes, often under the leadership of those individuals who have most to gain economically and socially from war. But for these factors, Schumpeter believed, imperialism would have been swept away into the dustbin of history as capitalist society ripened; for capitalism in its purest form is antithetical to imperialism: it thrives best with peace and free trade. Yet despite the innate peaceful nature of capitalism, interest groups do emerge that benefit from aggressive foreign conquests. Under monopoly capitalism the fusion of big banks and cartels creates a powerful and influential social group that pressures for exclusive control in colonies and protectorates, for the sake of higher profits.

Notwithstanding the resemblance between Schumpeter's discussion of monopoly and that of Lenin and other Marxists, a crucial difference does remain. Monopoly capitalism in Lenin's frame of reference is a natural outgrowth of the previous stage of competitive capitalism. But according to Schumpeter, it is an artificial graft on the more natural competitive capitalism, made possible by the catalytic effect of the residue from the preceding feudal society. Schumpeter argued that monopoly capitalism can only grow and prosper under the protection of high tariff walls; without that shield there would be large-scale industry but no cartels or other monopolistic arrangements. Because tariff walls are erected by political decisions, it is the state and not a natural economic process that promotes monopoly. Therefore, it is in the nature of the state—and especially those features that blend the heritage of the previous autocratic state, the old war machine, and feudal interests and ideas along with capitalist interests—that the cause of imperialism will be discovered. The particular form of imperialism in modern times is affected by capitalism, and capitalism itself is modified by the imperialist experience. In Schumpeter's analysis, however, imperialism is not an inevitable product of capitalism.

The state as the progenitor of imperialism

Quest for a general theory of imperialism. The main trend of academic thought in the Western world is to follow Schumpeter's conclusion—that modern imperialism is not a product of capitalism—without paying close attention to Schumpeter's sophisticated sociological analysis. Specialized studies have produced a variety of interpretations of the origin or reawakening of the new imperialism: for France, bolstering of national prestige after its defeat in the Franco-German War (1870–71); for Germany, Bismarck's design to stay in power when threatened by political rivals; for England, the desire for greater mili-

tary security in the Mediterranean and India. These reasons—along with other frequently mentioned contributing causes, such as the spirit of national and racial superiority and the drive for power—are still matters of controversy with respect to specific cases and to the problem of fitting them into a general theory of imperialism. For example, if it is found that a new colony was acquired for better military defense of existing colonies, the questions still remain as to why the existing colonies were acquired in the first place and why it was considered necessary to defend them rather than to give them up. Similarly, explanations in terms of the search for power still have to account for the close relationship between power and wealth, because in the real world adequate economic resources are needed for a nation to hold on to its power, let alone to increase it. Conversely, increasing a nation's wealth often requires power. As is characteristic of historical phenomena, imperialist expansion is conditioned by a nation's previous history and the particular situation preceding each expansionist move. Moreover, it is carried forth in the midst of a complex of political, military, economic, and psychological impulses. It would seem, therefore, that the attempt to arrive at a theory that explains each and every imperialist action—ranging from a semifeudal Russia to a relatively undeveloped Italy to an industrially powerful Germany—is a vain pursuit. But this does not eliminate the more important challenge of constructing a theory that will provide a meaningful interpretation of the almost simultaneous eruption of the new imperialism in a whole group of leading powers.

PENETRATION OF THE WEST IN ASIA

Russia's eastward expansion. European nations and Japan at the end of the 19th century spread their influence and control throughout the continent of Asia. Russia, because of its geographic position, was the only occupying power whose Asian conquests were overland. In that respect there is some similarity between Russia and the United States in the forcible outward push of their continental frontiers. But there is a significant difference: the United States advance displaced the indigenous population, with the remaining Indians becoming wards of the state. On the other hand, the Russian march across Asia resulted in the incorporation of alien cultures and societies as virtual colonies of the Russian Empire, while providing room for the absorption of Russian settlers.

Overland conquests

Although the conquest of Siberia and the drive to the Pacific had been periodically absorbing Russia's military energies since the 16th century, the acquisition of additional Asian territory and the economic integration of previously acquired territory took a new turn in the 19th century. Previously, Russian influence in its occupied territory was quite limited, without marked alteration of the social and economic structure of the conquered peoples. Aside from looting and exacting tribute from subject tribes, the major objects of interest were the fur trade, increased commerce with China and in the Pacific, and land. But changes in 19th-century Russian society, especially those coming after the Crimean War (1853–56), signalled a new departure. First, Russia's resounding defeat in that war temporarily frustrated its aspirations in the Balkans and the Near East; but, because its dynastic and military ambitions were in no way diminished, its expansionist energies turned with increased vigour to its Asian frontiers. Second, the emancipation of the serfs (1861), which eased the feudal restrictions on the landless peasants, led to large waves of migration by Russians and Ukrainians—first to Siberia and later to Central Asia. Third, the surge of industrialization, foreign trade, and railway building in the post-Crimean War decades paved the way for the integration of Russian Asia, which formerly, for all practical purposes, had been composed of separate dependencies, and for a new type of subjugation for many of these areas, especially in Central Asia, in which the conquered societies were "colonized" to suit the political and economic needs of the conqueror.

This process of acquisition and consolidation in Asia spread out in four directions: Siberia, the Far East, the Caucasus, and Central Asia. This pursuit of tsarist ambitions for empire and for warm-water ports involved numerous clashes and conflicts along the way. Russian expansion was ultimately limited not by the fierce opposition of the native population, which was at times a stumbling block, but by the counterpressure of competitive empire builders, such as Great Britain and Japan. Great Britain and Russia were mutually alarmed as the distances between the expanding frontiers of Russia and India shortened. One point of conflict was finally resolved when both powers agreed on the delimitation of the northern border of Afghanistan. A second major area of conflict in Central Asia was settled by an Anglo-Russian treaty (1907) to divide Persia into two separate spheres of influence, leaving a nominally independent Persian nation.

As in the case of Afghanistan and Persia, penetration of Chinese territory produced clashes with both the native government and other imperialist powers. At times China's preoccupation with its struggle against other invading powers eased the way for Russia's penetration. Thus, in 1860, when Anglo-French soldiers had entered Peking, Russia was able to wrest from China the Amur Province and special privileges in Manchuria (Northeast Provinces) south of the Amur River. With this as a stepping-stone, Russia took over the seacoast north of Korea and founded the town of Vladivostok. But, because the Vladivostok harbour is icebound for some four months of the year, the Russians began to pay more attention to getting control of the Korean coastline, where many good year-round harbours could be found. Attempts to acquire a share of Korea, as well as all of Manchuria, met with the resistance of Britain and Japan. Further thrusts into China beyond the Amur and maritime provinces were finally thwarted by defeat in 1905 in the Russo-Japanese War.

Penetration of China

The partitioning of China. The evolution of the penetration of Asia was naturally influenced by a multiplicity of factors—economic and political conditions in the expanding nations, the strategy of the military officials of the latter nations, the problems facing colonial rulers in each locality, pressures arising from white settlers and businessmen in the colonies, as well as the constraints imposed by the always limited economic and military resources of the imperialist powers. All these elements were present to a greater or lesser extent at each stage of the forward push of the colonial frontiers by the Dutch in Indonesia, the French in Indochina (Vietnam, Laos, Cambodia), and the British in Malaya, Burma, and Borneo.

Yet, despite the variety of influences at work, three general types of penetration stand out. One of these is expansion designed to overcome resistance to foreign rule. Resistance, which assumed many forms ranging from outright rebellion to sabotage of colonial political and economic domination, was often strongest in the border areas farthest removed from the centres of colonial power. The consequent extension of military control to the border regions tended to arouse the fears and opposition of neighbouring states or tribal societies and thus led to the further extension of control. Hence, attempts to achieve military security prompted the addition of border areas and neighbouring nations to the original colony.

A second type of expansion was a response to the economic opportunities offered by exploitation of the colonial interiors. Traditional trade and the free play of market forces in Asia did not produce huge supplies of raw materials and food or the enlarged export markets sought by the industrializing colonial powers. For this, entrepreneurs and capital from abroad were needed, mines and plantations had to be organized, labour supplies mobilized, and money economies created. All these alien intrusions functioned best under the firm security of an accommodating alien law and order.

The third type of expansion was the result of rivalry among colonial powers. When possible, new territory was acquired or old possessions extended in order either to preclude occupation by rivals or to serve as buffers for military security against the expansions of nearby colonial powers. Where the crosscurrents of these rivalries prevented any one power from obtaining exclusive control, various substitute arrangements were arrived at: parts of a country were chipped off and occupied by one or

more of the powers; spheres of influence were partitioned; unequal commerical treaties were imposed—while the countries subjected to such treatment remained nominally independent.

The penetration of China is the outstanding example of this type of expansion. In the early 19th century the middle part of eastern Asia (Japan, Korea, and China), containing about half the Asian population, was still little affected by Western penetration. By the end of the century, Korea was on the way to becoming annexed by Japan, which had itself become a leading imperialist power. China remained independent politically, though it was already extensively dominated by outside powers. Undoubtedly, the intense rivalry of the foreign powers helped save China from being taken over outright (as India had been). China was pressed on all sides by competing powers anxious for its trade and territory: Russia from the north, Great Britain (via India and Burma) from the south and west, France (via Indochina) from the south, and Japan and the United States (in part, via the Philippines) from the east.

Rivalry over China

The Opium Wars. The first phase of the forceful penetration of China by western Europe came in the two Opium Wars. Great Britain had been buying increasing quantities of tea from China, but it had few products that China was interested in buying by way of exchange. A resulting steady drain of British silver to pay for the tea was eventually stopped by Great Britain's ascendancy in India. With British merchants in control of India's foreign trade and with the financing of this trade centred in London, a three-way exchange developed: the tea Britain bought in China was paid for by India's exports of opium and cotton to China. And because of a rapidly increasing demand for tea in England, British merchants actively fostered the profitable exports of opium and cotton from India.

An increasing Chinese addiction to opium fed a boom in imports of the drug and led to an unfavourable trade balance paid for by a steady loss of China's silver reserves. In light of the economic effect of the opium trade plus the physical and mental deterioration of opium users, Chinese authorities banned the opium trade. At first this posed few obstacles to British merchants, who resorted to smuggling. But enforcement of the ban became stringent toward the end of the 1830s; stores of opium were confiscated, and warehouses were closed down. British merchants had an additional and longstanding grievance because the Chinese limited all trade by foreigners to the port of Canton.

In June 1840 the British fleet arrived at the mouth of the Canton River to begin the Opium War. The Chinese capitulated in 1842 after the fleet reached the Yangtze, Shanghai fell, and Nanking was under British guns. The resulting Treaty of Nanking—the first in a series of commercial treaties China was forced to sign over the years—provided for: (1) cession of Hong Kong to the British crown; (2) the opening of five treaty ports, where the British would have residence and trade rights; (3) the right of British nationals in China who were accused of criminal acts to be tried in British courts; and (4) the limitation of duties on imports and exports to a modest rate. Other countries soon took advantage of this forcible opening of China; in a few years similar treaties were signed by China with the United States, France, and Russia.

Opening of China

The Chinese, however, tried to retain some independence by preventing foreigners from entering the interior of China. With the country's economic and social institutions still intact, markets for Western goods, such as cotton textiles and machinery, remained disappointing: the self-sufficient communities of China were not disrupted as those in India had been under direct British rule, and opium smuggling by British merchants continued as a major component of China's foreign trade. Western merchants sought further concessions to improve markets. But meanwhile China's weakness, along with the stresses induced by foreign intervention, was further intensified by an upsurge of peasant rebellions, especially the massive 14-year Taiping Rebellion (1850–64).

The Western powers took advantage of the increasing difficulties by pressing for even more favourable trade treaties, culminating in a second war against China (1856–60), this time by France and England. Characteristically, the Western powers invading China played a double role: in addition to forcing a new trade treaty, they also helped to sustain the Chinese ruling establishment by participating in the suppression of the Taiping Rebellion; they believed that a Taiping victory would result in a reformed and centralized China, more resistant to Western penetration. China's defeat in the second war with the West produced a series of treaties, signed at Tientsin with Britain, France, Russia, and the United States, which brought the Western world deeper into China's affairs. The Tientsin treaties provided, among other things, for the right of foreign nationals to travel in the interior, the right of foreign ships to trade and patrol on the Yangtze River, the opening up of more treaty ports, and additional exclusive legal jurisdiction by foreign powers over their nationals residing in China.

Foreign privileges in China. Treaties of this general nature were extended over the years to grant further privileges to foreigners. Furthermore, more and more Western nations—including Germany, Italy, Denmark, The Netherlands, Spain, Belgium, and Austria-Hungary—took advantage of the new opportunities by signing such treaties. By the beginning of the 20th century, some 90 Chinese ports had been opened to foreign control. While the Chinese government retained nominal sovereignty in these ports, de facto rule was exercised by one or more of the powers: in Shanghai, for example, Great Britain and the United States coalesced their interests to form the Shanghai International Settlement. In most of the treaty ports, China leased substantial areas of land at low rates to foreign governments. The consulates in these concessions exercised legal jurisdiction over their nationals, who thereby escaped China's laws and tax collections. The foreign settlements had their own police forces and tax systems and ran their own affairs independently of nominally sovereign China.

These settlements were not the only intrusion on China's sovereignty. In addition, the opium trade was finally legalized, customs duties were forced downward to facilitate competition of imported Western goods, foreign gunboats patrolled China's rivers, and aliens were placed on customs-collection staffs to ensure that China would pay the indemnities imposed by various treaties. In response to these indignities and amid growing antiforeign sentiment, the Chinese government attempted reforms to modernize and develop sufficient strength to resist foreign intrusions. Steps were taken to master Western science and technology, erect shipyards and arsenals, and build a more effective army and navy. The reforms, however, did not get very far: they did not tackle the roots of China's vulnerability, its social and political structure; and they were undertaken quite late, after foreign nations had already established a strong foothold. Also, it is likely that the reforms were not wholehearted because two opposing tendencies were at play: on the one hand, a wish to seek independence and, on the other hand, a basic reliance on foreign support by a weak Manchu government beset with rebellion and internal opposition.

Chinese attempts at modernization

The Open Door Policy. In any event, preliminary attempts to Westernize Chinese society from within did not deter further foreign penetration; nor did the subsequent revolution (1911) succeed in freeing China from Western domination. Toward the end of the 19th century, under the impact of the new imperialism, the spread of foreign penetration accelerated. Germany entered a vigorous bid for its sphere of influence; Japan and Russia pushed forward their territorial claims; and U.S. commercial and financial penetration of the Pacific, with naval vessels patrolling Chinese rivers, was growing rapidly. But at the same time this mounting foreign interest also inhibited the outright partition of China. Any step by one of the powers toward outright partition or sizable enlargement of its sphere of influence met with strong opposition from other powers. This led eventually to the Open Door Policy, advocated by the United States, which limited or restricted exclusive privileges of any one power vis-à-vis the others. It became generally accepted after the anti-foreign Boxer Rebellion (1900) in China. With the foreign armies that had been brought in to suppress the rebellion now stationed in

North China, the danger to the continued existence of the Chinese government and the danger of war among the imperialist powers for their share of the country seemed greater than ever. Agreement on the Open Door Policy helped to retain both a compliant native government and equal opportunity for commerce, finance, and investment by the more advanced nations.

Japanese resistance to colonization

Japan's rise as a colonial power. Japan was the only Asian country to escape colonization from the West. European nations and the United States tried to "open the door," and to some extent they succeeded; but Japan was able to shake off the kind of subjugation, informal or formal, to which the rest of Asia succumbed. Even more important, it moved onto the same road of industrialization as did Europe and the United States. And instead of being colonized it became one of the colonial powers.

Japan had traditionally sought to avoid foreign intrusion. For many years, only the Dutch and the Chinese were allowed trading depots, each having access to only one port. No other foreigners were permitted to land in Japan, though Russia, France, and England tried, but with little success. The first significant crack in Japan's trade and travel barriers was forced by the United States in an effort to guarantee and strengthen its shipping interests in the Far East. Japan's guns and ships were no match for those of Commodore Perry in his two U.S. naval expeditions to Japan (1853, 1854).

The Japanese, well aware of the implications of foreign penetration through observing what was happening to China, tried to limit Western trade to two ports. In 1858, however, Japan agreed to a full commercial treaty with the United States, followed by similar treaties with the Low Countries, Russia, France, and Britain. The treaty pattern was familiar: more ports were opened; resident foreigners were granted extraterritorial rights, as in China; import and export duties were predetermined, thus removing control that Japan might otherwise exercise over its foreign trade.

Many attempts have been made to explain why a weak Japan was not taken over as a colony or, at least, did not follow in China's footsteps. Despite the absence of a commonly accepted theory, two factors were undoubtedly crucial. On the one hand, the Western nations did not pursue their attempts to control Japan as aggressively as they did elsewhere. In Asia the interests of the more aggressively expanding powers had centred on India, China, and the immediately surrounding areas. When greater interest developed in a possible breakthrough in Japan in the 1850s and 1860s, the leading powers were occupied with other pressing affairs, such as thhe 1857 Indian mutiny, the Taiping Rebellion, the Crimean War, French intervention in Mexico, and the U.S. Civil War. International jealousy may also have played a role in deterring any one power from trying to gain exclusive control over the country. On the other hand, in Japan itself, the danger of foreign military intervention, a crisis in its traditional feudal society, the rise of commerce, and a disaffected peasantry led to an intense internal power struggle and finally to a revolutionary change in the country's society and a thoroughgoing modernization program, one that brought Japan the economic and military strength to resist foreign nations.

The Meiji Restoration

The opposing forces in Japan's civil war were lined up between the supporters of the ruling Tokugawa family, which headed a rigid hierarchical feudal society, and the supporters of the emperor Meiji, whose court had been isolated from any significant government role. The civil war culminated in 1868 in the overthrow of the Tokugawa government and the restoration of the rule of the Emperor. The Meiji Restoration also brought new interest groups to the centre of political power and instigated a radical redirection of Japan's economic development. The nub of the changeover was the destruction of the traditional feudal social system and the building of a political, social, and economic framework conducive to capitalist industrialization. The new state actively participated in the turnabout by various forms of grants and guarantees to enterprising industrialists and by direct investment in basic industries such as railways, shipbuilding, communications, and machinery. The concentration of resources in the industrial sector was matched by social reforms that eliminated feudal restrictions, accelerated mass education, and encouraged acquisition of skills in the use of Western technology. The ensuing industrialized economy provided the means for Japan to hold its own in modern warfare and to withstand foreign economic competition.

Soon Japan not only followed the Western path of internal industrialization, but it also began an outward aggression resembling that of the European nations. First came the acquisition and colonization of neighbouring islands: Ryukyu Islands (including Okinawa), the Kuril Islands, Bonin Islands, and Hokkaido. Next in Japan's expansion program was Korea, but the opposition of other powers postponed the transformation of Korea into a Japanese colony. The pursuit of influence in Korea involved Japan in war with China (1894–95), at the end of which China recognized Japan's interest in Korea and ceded to Japan Taiwan, the Pescadores, and southern Manchuria. At this point rival powers interceded to force Japan to forgo taking over the southern Manchuria peninsula. While France, Britain, and Germany were involved in seeking to frustrate Japan's imperial ambitions, the most direct clash was with Russia over Korea and Manchuria. Japan's defeat of Russia in the war of 1904–05 procured for Japan the lease of the Liaotung Peninsula, the southern part of the island of Sakhalin, and recognition of its "paramount interest" in Korea. Still, pressure by Britain and the United States kept Japan from fulfillment of its plan to possess Manchuria outright. By the early 20th century, however, Japan had, by means of economic and political penetration, attained a privileged position in that part of China, as well as colonies in Korea and Taiwan and neighbouring islands.

PARTITION OF AFRICA

By the turn of the 20th century, the map of Africa looked like a huge jigsaw puzzle, with most of the boundary lines having been drawn in a sort of game of give-and-take played in the foreign offices of the leading European powers. The division of Africa, the last continent to be so carved up, was essentially a product of the new imperialism, vividly highlighting its essential features. In this respect, the timing and the pace of the scramble for Africa are especially noteworthy. Before 1880 colonial possessions in Africa were relatively few and limited to coastal areas, with large sections of the coastline and almost all the interior still independent. By 1900 Africa was almost entirely divided into separate territories that were under the administration of European nations. The only exceptions were Liberia, generally regarded as being under the special protection of the United States; Morocco, conquered by France a few years later; Libya, later taken over by Italy; and Ethiopia.

The second feature of the new imperialism was also strongly evident. It was in Africa that Germany made its first major bid for membership in the club of colonial powers: between May 1884 and February 1885, Germany announced its claims to territory in South West Africa (now South West Africa/Namibia), Togoland, Cameroon, and part of the East African coast opposite Zanzibar. Two smaller nations, Belgium and Italy, also entered the ranks, and even Portugal and Spain once again became active in bidding for African territory. The increasing number of participants in itself sped up the race for conquest. And with the heightened rivalry came more intense concern for preclusive occupation, increased attention to military arguments for additional buffer zones, and, in a period when free trade was giving way to protective tariffs and discriminatory practices in colonies as well as at home, a growing urgency for protected overseas markets. Not only the wish but also the means were at hand for this carving up of the African pie. Repeating rifles, machine guns, and other advances in weaponry gave the small armies of the conquering nations the effective power to defeat the much larger armies of the peoples of Africa. Rapid railroad construction provided the means for military, political, and economic consolidation of continental interiors. With the new steamships, settlers and materials could be moved to Africa with greater dispatch, and bulk shipments of raw

materials and food from Africa, prohibitively costly for some products in the days of the sailing ship, became economically feasible and profitable.

Penetration of Islāmic North Africa was complicated, on the one hand, by the struggle among European powers for control of the Mediterranean Sea and, on the other hand, by the suzerainty that the Ottoman Empire exercised to a greater or lesser extent over large sections of the region. Developments in both respects contributed to the wave of partition toward the end of the 19th century. First, Ottoman power was perceptibly waning: the military balance had tipped decisively in favour of the European nations, and Turkey was becoming increasingly dependent on loans from European centres of capital (in the late 1870s Turkey needed half of its government income just to service its foreign debt). Second, the importance of domination of the Mediterranean increased significantly after the Suez Canal was opened in 1869.

French penetration of North Africa

France was the one European nation that had established a major beachhead in Islāmic North Africa before the 1880s. At a time when Great Britain was too preoccupied to interfere, the French captured the fortress of Algiers in 1830. Frequent revolts kept the French Army busy in the Algerian interior for another 50 years before all Algeria was under full French rule. While Tunisia and Egypt had been areas of great interest to European powers during the long period of France's Algerian takeover, the penetration of these countries had been informal, confined to diplomatic and financial manoeuvres. Italy, as well as France and England, had loaned large sums to the ruling *beys* of Tunisia to help loosen that country's ties with Turkey. The inability of the *beys* to service the foreign debt in the 1870s led to the installation of debt commissioners by the lenders. Tunisia's revenues were pledged to pay the interest due on outstanding bonds; in fact, the debt charges had first call on the government's income. With this came increased pressure on the people for larger tax payments and a growing popular dissatisfaction with a government that had "sold out" to foreigners. The weakness of the ruling group, intensified by the danger of popular revolt or a military coup, opened the door further for formal occupation by one of the interested foreign powers. When Italy's actions showed that it might be preparing for outright possession, France jumped the gun by invading Tunisia in 1881 and then completed its conquest by defeating the rebellions precipitated by this occupation.

The Europeans in North Africa. The course of Egypt's loss of sovereignty resembled somewhat the same process in Tunisia: easy credit extended by Europeans, bankruptcy, increasing control by foreign-debt commissioners, mulct-



The European partition of Africa.

ing of the peasants to raise revenue for servicing the debt, growing independence movements, and finally military conquest by a foreign power. In Egypt, inter-imperialist rivalry, mainly between Great Britain and France, reached back to the early 19th century but was intensified under the circumstances of the new imperialism and the construction of the Suez Canal. By building the Suez Canal and financing Egypt's ruling group, France had gained a prominent position in Egypt. But Britain's interests were perhaps even more pressing because the Suez Canal was a strategic link to its empire and its other Eastern trade and colonial interests. The successful nationalist revolt headed by the Egyptian army imminently threatened in the 1880s the interests of both powers. France, occupied with war in Tunisia and with internal political problems, did not participate in the military intervention to suppress the revolt. Great Britain bombarded Alexandria in 1882, landed troops, and thus obtained control of Egypt. Unable to find a stable collaborationist government that would also pay Egypt's debts and concerned with suppressing not only the rebellion but also a powerful anti-Egyptian Mahdist revolt in the Sudan, Britain completely took over the reins of government in Egypt.

The rest of North Africa was carved up in the early 20th century. France, manoeuvring for possession of Morocco, which bordered on her Algerian colony, tried to obtain the acquiescence of the other powers by both secret and open treaties granting Italy a free hand in Libya, allotting to Spain a sphere of influence, and acknowledging Britain's paramountcy in Egypt. France had, however, overlooked Germany's ambitions, now backed by an increasingly effective army and navy. The tension created by Germany led to an international conference at Algeciras (1906), which produced a short-lived compromise, including recognition of France's paramount interest, Spanish participation in policing Morocco, and an open door for the country's economic penetration by other nations. But France's vigorous pursuit of her claims, reinforced by the occupation of Casablanca and surrounding territory, precipitated critical confrontations, which reached their peak in 1911 when French troops were suppressing a Moroccan revolt and a German cruiser appeared before Agadir in a show of force. The resulting settlements completed the European partition of North Africa: France obtained the lion's share of Morocco; in return, Germany received a large part of the French Congo; Italy was given the green light for its war with Turkey over control of Tripoli, the first step in its eventual acquisition of Libya; and Spain was enabled to extend its Río de Oro protectorate to the southern frontier of Morocco. The more or less peaceful trade-offs by the occupying powers differed sharply from the long, bitter, and expensive wars they waged against the indigenous peoples and rulers of Islāmic North Africa to solidify European rule.

The race for colonies in sub-Saharan Africa. The partition of Africa below the Sahara took place at two levels: (1) on paper—in deals made among colonial powers who were seeking colonies partly for the sake of the colonies themselves and partly as pawns in the power play of European nations struggling for world dominance—and (2) in the field—in battles of conquest against African states and tribes and in military confrontations among the rival powers themselves. This process produced, over and above the ravages of colonialism, a wasp's nest of problems that was to plague African nations long after they achieved independence. Boundary lines between colonies were often drawn arbitrarily, with little or no attention to ethnic unity, regional economic ties, tribal migratory patterns, or even natural boundaries.

Colonies in West Africa

Before the race for partition, only three European powers—France, Portugal, and Britain—had territory in tropical Africa, located mainly in West Africa. Only France had moved into the interior along the Sénégal River. The other French colonies or spheres of influence were located along the Ivory Coast and in Dahomey (now Benin) and Gabon. Portugal held on to some coastal points in Angola, Mozambique (Moçambique), and Portuguese Guinea (now Guinea-Bissau). While Great Britain had a virtual protectorate over Zanzibar in East Africa, its actual possessions were on the west coast in the Gambia, the Gold Coast, the Sierra Leone, all of them surrounded by African states that had enough organization and military strength to make the British hesitate about further expansion. Meanwhile, the ground for eventual occupation of the interior of tropical Africa was being prepared by explorers, missionaries, and traders. But such penetration remained tenuous until the construction of railroads and the arrival of steamships on navigable waterways made it feasible for European merchants to dominate the trade of the interior and for European governments to consolidate conquests.

Once conditions were ripe for the introduction of railroads and steamships in West Africa, tensions between the English and French increased as each country tried to extend its sphere of influence. As customs duties, the prime source of colonial revenue, could be evaded in uncontrolled ports, both powers began to stretch their coastal frontiers, and overlapping claims and disputes soon arose. The commercial penetration of the interior created additional rivalry and set off a chain reaction. The drive for exclusive control over interior areas intensified in response to both economic competition and the need for protection from African states resisting foreign intrusion. This drive for African possessions was intensified by the new entrants to the colonial race who felt menaced by the possibility of being completely locked out.

Perhaps the most important stimulants to the scramble for colonies south of the Sahara were the opening up of the Congo Basin by Belgium's king Leopold II and Germany's energetic annexationist activities on both the east and west coasts. As the dash for territory began to accelerate, 15 nations convened in Berlin in 1884 for the West African Conference, which, however, merely set ground rules for the ensuing intensified scramble for colonies. It also recognized the Congo Free State ruled by King Leopold, while insisting that the rivers in the Congo Basin be open to free trade. From his base in the Congo, the King subsequently took over mineral-rich Katanga, transferring both territories to Belgium in 1908.

In West Africa, Germany concentrated on consolidating its possessions of Togoland and Cameroon (Kamerun), while England and France pushed northward and eastward from their bases: England concentrated on the Niger region, the centre of its commercial activity, while France aimed at joining its possessions at Lake Chad within a grand design for an empire of contiguous territories from Algeria to the Congo. Final boundaries were arrived at after the British had defeated, among others, the Ashanti, the Fanti Confederation, the Opobo kingdom, and the Fulani; and the French won wars against the Fon kingdom, the Tuareg, the Mandingo, and other resisting tribes. The boundaries determined by conquest and agreement between the conquerors gave France the lion's share: in addition to the extension of its former coastal possessions, France acquired French West Africa and French Equatorial Africa, while Britain carved out its Nigerian colony.

In southern Africa, the intercolonial rivalries chiefly involved the British, the Portuguese, the South African Republic of the Transvaal, the British-backed Cape Colony, and the Germans. The acquisitive drive was enormously stimulated by dreams of wealth generated by the discovery of diamonds in Griqualand West and gold in Matabeleland. Encouraged by these discoveries, Cecil Rhodes (heading the British South Africa Company) and other entrepreneurs expected to find gold, copper, and diamonds in the regions surrounding the Transvaal, among them Bechuanaland, Matabeleland, Mashonaland, and Trans-Zambezia. In the ensuing struggle, which involved the conquest of the Nbele and Shona peoples, Britain obtained control over Bechuanaland and, through the British South Africa Company, over the areas later designated as the Rhodesias and Nyasaland. At the same time, Portugal moved inland to seize control over the colony of Mozambique. It was clearly the rivalries of stronger powers, especially the concern of Germany and France over the extension of British rule in southern Africa, that enabled a weak Portugal to have its way in Angola and Mozambique.

Rivalry in East Africa

The boundary lines in East Africa were arrived at largely in settlements between Britain and Germany, the two chief rivals in that region. Zanzibar and the future Tanganyika were divided in the Anglo-German treaty of 1890: Britain obtained the future Uganda and recognition of its paramount interest in Zanzibar and Pemba in exchange for ceding the strategic North Sea island of Heligoland (Helgoland) and noninterference in Germany's acquisitions in Tanganyika, Rwanda, and Urundi. Britain began to build an East African railroad to the coast, establishing the East African Protectorate (later Kenya) over the area where the railroad was to be built.

Rivalry in northeastern Africa between the French and British was based on domination of the upper end of the Nile. Italy had established itself at two ends of Ethiopia, in an area on the Red Sea that the Italians called Eritrea and in Italian Somaliland along the Indian Ocean. Italy's inland thrust led to war with Ethiopia and defeat at the hands of the Ethiopians at Adowa (1896). Ethiopia, surrounded by Italian and British armies, had turned to French advisers. The unique victory by an African state over a European army strengthened French influence in Ethiopia and enabled France to stage military expeditions from Ethiopia as well as from the Congo in order to establish footholds on the Upper Nile. The resulting race between British and French armies ended in a confrontation at Fashoda in 1898, with the British army in the stronger position. War was narrowly avoided in a settlement that completed the partition of the region: eastern Sudan was to be ruled jointly by Britain and Egypt, while France was to have the remaining Sudan from the Congo and Lake Chad to Darfur.

Germany's entrance into southern Africa through occupation and conquest of South West Africa touched off an upsurge of British colonial activity in that area, notably the separation of Basutoland (Lesotho) as a crown colony from the Cape Colony and the annexation of Zululand. As a consequence of the South African (Boer) War (1899–1902) Britain obtained sovereignty over the Transvaal and the Afrikaner Orange Free State. (Ha.Ma.)

WORLD WAR I AND THE INTERWAR PERIOD (1914–39)

Postwar redistribution of colonies. After World War I the Allied powers partitioned among themselves both the German overseas colonial holdings and the vast Arab provinces of the Ottoman Empire. They carried out this operation through the League of Nations, which awarded mandates under varying conditions. Great Britain received as mandates Iraq and Palestine (which it promptly split into Transjordan and Palestine proper); the Palestine mandate obligated Britain to respect its contradictory wartime commitments to both Jews and Arabs. France assumed a mandate over both Syria and Lebanon. In Africa the two powers divided Togo and Cameroon between them, Britain acquired Tanganyika (with a few thousand German settlers), Belgium took Rwanda–Urundi, and South Africa received German South West Africa. Italy, as compensation for not sharing in the award of mandates, obtained from Britain the Juba (Giuba) Valley on the Kenya–Somali frontier, and France eventually ceded to Italy a desert area that rounded out Libya's southern frontiers.

League mandates

The interwar years marked the apex of colonial empires throughout the world, and indirect forms of colonial penetration grew with the development of the petroleum industry. Nevertheless, most colonial systems began to show clear signs of strain and even revolt. The Russian Revolution, the Nationalist and Communist successes in China during the 1920s and '30s, the radical nationalism of Kemal Atatürk, all contributed to the rise of political movements opposed to colonialism. The very process of economic modernization, however—with the rise of factories, coordination with the world market, and mass urbanization—did more than any political or cultural factor, taken in itself, to undermine the paternal-militaristic forms of direct colonial domination.

The British Empire. Britain tended toward a decentralized and empirical type of colonial administration, in which some degree of partial decolonization could prepare the way for eventual self-rule. Realizing that direct rule over ancient civilized lands could not last indefinitely, Britain worked for a continued British presence in areas where the empire conferred self-government.

Middle East. At the outset of World War I, Britain had proclaimed a protectorate over Egypt, annulling Ottoman sovereignty; afterward, Egyptian nationalist leaders finally brought the British to recognize Egypt as an independent kingdom in 1922. In 1936–37 Egypt received control over its own economic development, and British military forces were confined to the Suez Canal area. Britain granted Iraq independence in 1932 but retained a military power base in the new kingdom. Both the world strategic balance and the British petroleum industry ruled out any possibility of a real British withdrawal from either of these Middle Eastern states. Egypt

In Palestine the political claims of Arabs and Jews proved to be irreconcilable, and insurrection, terrorism, and occasional guerrilla warfare marked the whole period of British rule. Finally, in 1939, with war looming, the British decided to limit and eventually terminate the flow of Jewish refugees into Palestine, though not proposing to force the more than 500,000 Jewish inhabitants to live under an Arab national regime. Transjordan, detached from Palestine, became a British protectorate.

India. In India Britain faced a powerful adversary, the Indian National Congress, uniting businessmen and working classes, Hindus of high and low caste, in a common drive toward independence. The Congress never, however, succeeded in bridging the gap that separated the country's Hindu and Sikh majority from its 90,000,000 Muslims. The British met the Indian anticolonial movement half way. In 1919–23 a series of measures gave the Indians a certain degree of self-rule in a "dyarchy" in which elected Indian ministers governed together with British administrators. These constitutional reforms, however, failed to bring the princely states into line with the new trend toward self-rule. Though Mahatma Gandhi denounced the new system as a "whited sepulchre," Congress in fact began to participate in the governmental process. Under the constitution granted in 1935–37, the British maintained separate voting rolls for the Muslim minority, in order to ensure its proportional representation; in 1939 relations between Britain and the Congress Party were tense, but India was clearly headed for independence in some form. Indian dyarchy

In 1937 the British gave a separate constitution to Burma. Ceylon (renamed Sri Lanka in 1972) had been separate and self-governing from 1931.

Africa. In British Africa decolonization progressed more slowly, but London began to accept it as an ultimate outcome. In Kenya, for example, the British government refused to grant the 20,000 European settlers in the "white highlands" any kind of direct political power over the mass of tribal blacks who constituted the colony's overwhelming majority. In British West Africa the passage from direct colonial government to self-rule by a black elite had started by 1939, there being no white settlers or Indian merchants (as there were in East Africa) to complicate matters. Only in the mining areas of Northern Rhodesia (the Copperbelt) and in Southern Rhodesia, where white farmer settlers enjoyed self-government and caste privileges over a disenfranchised black majority, did decolonization make no headway at all.

Overseas France. France, in contrast to Britain, preferred centralized and assimilative methods in an effort to integrate its colonies into a greater Overseas France. It made no progress in colonial devolution and refused even to grant independence to Syria and Lebanon. In North Africa the French energetically implanted large agrarian capitalist enterprises as well as some industries connected with the area's mineral wealth. These modern production centres and infrastructures were directed and financed by metropolitan French business and were staffed and operated by a large, politically aggressive European settler population. The Muslim majority was subordinate both politically and economically; North African peasants struggled to subsist on the margins. Overt resistance was strongest in Morocco, where a rural Muslim rebellion endangered both the French and the Spanish protectorates. Abd el-Krim, a Berber Moroccan leader who combined tradition with Abd el-Krim

modern nationalism, waged a brilliant five-year campaign till a combined French and Spanish force finally defeated him in 1926. After 1934, resistance to France revived in Morocco, this time in the cities. In Tunisia resistance was centred in Habib Bourguiba's constitutional party; in Algeria the urban Muslim middle classes merely asked for true civil rights and integration. The French Communist Party did not move to mobilize the peasant masses in an anticolonial struggle, and, in consequence, future rebellion in the Maghrib was to be Arab nationalist and not Marxist in its leadership and doctrines.

Matters were different in French Indochina, where the growth of a modern, French-directed agricultural economy had thrown masses of peasants into debt slavery. The circumstances favoured the formation of an independence movement much influenced by both the Chinese Kuomintang (Nationalist Party) and the Chinese Communist Party; the movement in the 1930s took the form of a Communist party under the leadership of Ho Chi Minh.

French sub-Saharan Africa attracted no European settler population. The French colonial authorities promoted a shift from subsistence to market economies, and their methods, including labour conscription for public works, led to protest and questions in the French parliament. The results, guaranteed by a protective tariff linking the colonies to France, were solid but unspectacular.

Axis Powers. In the 1930s an aggressive new colonialism devoloped on the part of the Axis Powers, which developed a new colonial doctrine ("living space" in German geopolitics, the "empire" in Italian Fascist ideology, the "co-prosperity sphere" in Japan) aiming at the repartition of the world's colonial areas, justified by the supposed racial superiority, higher birth rates, and greater productivity that the Axis Powers enjoyed as against the "decadent" West. To this the Japanese added a slogan of their own, "Asia for the Asians." In fact, the three powers aimed at carving out for themselves vast, self-sufficient empires. Though intent on a new colonialism of their own, they had to use anticolonialism as a political instrument before and during World War II; in doing so, they helped in the process of world decolonization.

Fascist Italy's first colonial war was a long, bloody campaign in Cyrenaica that lasted until the early 1930s, when Italy began developing Libya as a place of settlement for Italian peasants. Then a dispute over the border between Italian Somaliland and Ethiopia (1934) gave the Italian dictator, Benito Mussolini, the opportunity to move against the African power that had routed Italian armies at Adowa. In October 1935 Italian troops from Eritrea moved into the Tigre province of northern Ethiopia, although war was never declared. Ethiopia, underequipped and feudal, could not long hold out in open combat, especially against Italian air attacks. In May 1936 Italian motorized columns reached Addis Ababa, and the Emperor went into exile. Mussolini proclaimed the Italian "empire" in East Africa. In reality, however, Ethiopian feudal chiefs continued violent resistance, even in the environs of the capital, while the Italians massacred hundreds of nobles, clergy, and commoners in an effort to repress Ethiopia by terror. In this their success was limited. The Italians built roads and kept control over all principal communication lines, but they never subdued the mountainous hinterland.

Italy in Ethiopia

The Greater East Asia Co-prosperity Sphere, Japan's new order, amounted to a self-contained empire from Manchuria to the Dutch East Indies, including China, Indochina, Thailand, and Malaya as satellite states. Japan intended to exclude both European imperialism and Communist influence from the entire Far East, while ensuring Japanese political and industrial hegemony.

The United States and the Soviet Union. During World War I the United States purchased the Virgin Islands from Denmark (1917), but it acquired no new colonies thereafter. In the 1920s the United States agreed to leave unfortified its possessions beyond Hawaii, in exchange for Japan's accepting naval limitations. The Philippines, by the Tydings–McDuffie Act of 1934, were to become independent on July 4, 1946. Until U.S.–Japanese relations began to worsen, in 1939, U.S. possessions in the Pacific counted for little in world affairs. On the other hand, the United States established or continued virtual protectorates in Cuba, Haiti, the Dominican Republic, Nicaragua, and Panama during the Harding and Coolidge administrations (1921–29), a trend reversed under Hoover and Roosevelt, particularly under the latter's Good Neighbor Policy toward Latin America.

Roosevelt's Good Neighbor Policy

The new Soviet Russian regime succeeded, after years of civil and foreign war, in regaining the Asian possessions of its tsarist predecessor. The Caucasus was repossessed step by step between 1919 and 1921; after the mountain areas and Azerbaijan were brought back under Soviet control, Armenia was partitioned between Russia and Turkey. Then Georgia, an independent parliamentary republic, was overrun by the Red Army. Russian Turkistan was subdued by 1922, and the khanates of Khiva and Bukhara were suppressed. By 1922, Outer Mongolia was also solidly linked to the Soviet state. Nevertheless, the Russian revolutionary government was ideologically opposed to colonialism, especially where it had no colonial interests that it cared to defend. In general, the Soviet authorities hesitated during the interwar period between the alternatives of backing liberation movements of "national bourgeoisies" and supporting peasant revolutionary parties.

In Central Asia the Soviet authorities followed a moderate line up to 1928, but with the advent of Stalin a new policy, consisting in purges of national leaders, increasing industrialization, and forced settlement of nomad populations, led to a great increase in the proportion of European settlers, mostly Russians and Ukrainians, to native Muslims. During the 1930s the Kazakhs declined sharply in absolute numbers as well as in ratio to the Europeans in their areas. Other Muslim nationalities, especially the Uzbeks, stemmed the Slavic tide of settlement only by virtue of their birth rates, which greatly exceeded those of the Russians and Ukrainians.

WORLD WAR II (1939–45)

Although the Axis Powers failed in their global strategy, they crippled European colonial rule in Asia.

Asia. Japan conquered its Greater East Asia Co-prosperity Sphere and arrived at the gates of India, displacing British, Dutch, and French colonial rulers as well as the Americans in Guam and the Philippines. The Japanese had to allow some margin of freedom to their satellite regimes in Burma and Indonesia in both of which preexisting local parties proved capable of creating sovereign states after the war. On August 17, 1945, Sukarno declared Indonesia independent. Indonesia had had a long history of Muslim, nationalist, and Communist agitation against the Dutch; with captured Japanese arms, Indonesia could resist reimposition of Dutch authority.

Indonesian independence

In India the Congress Party, though totally unsympathetic to the Axis, tried to take advantage of Britain's wartime extremity in order to secure immediate independence. The Muslim League supported the British administration during the war but demanded a sovereign Muslim homeland (Pakistan) as a postwar objective. By 1945 direct British rule in India was coming to an end, but the contest between Britain, the Congress Party, and the Muslim League clouded any final settlement.

Middle East. In the Middle East, Britain returned to forms of direct colonial control as Axis forces drew near, and in June–July 1941 it occupied Syria and Lebanon, under the guise of Free French administration. With Beirut and Damascus secured, the British supported Syrian and Lebanese independence from France; the two states were incorporated into the sterling area. Only U.S. and Soviet support guaranteed the independence of the two republics (1944) and their subsequent admission to the United Nations.

In Egypt, when Axis forces in 1941 and 1942 came within striking distance of Alexandria, both the king, Farouk, and groups of dissident army officers were ready to welcome them and turn against the British. In February 1942 the British minister forced the King to appoint a government willing to cooperate with the Anglo-Americans; the defeat of the Germans in the Egyptian desert later that year put Egypt firmly in the Allied camp. Nevertheless much anti-

British and anticolonial bitterness remained in Egypt, with postwar consequences.

Iran

At the outset of World War II Iran was pro-German, and in August 1941 the Soviet Union and Britain jointly occupied the country, which then became the main supply line connecting the Soviet Union with the Western Allies. In 1942, in a three-power treaty, both Britain and the Soviet Union promised to leave Iran six months after the end of the war. Notwithstanding such commitments, the Soviet Union began to build spheres of influence in northern Iran; in 1944 the Soviet Union brought pressure to bear on Iran for an oil concession.

During the final years of World War II the United States became vitally interested in the Middle East because of United States petroleum ventures in Saudi Arabia and because of strategic considerations. By the end of the war it was clear to both the Soviet Union and Britain that the United States, as a world power, would support no imposition of direct colonial controls in the postwar Middle East.

Africa. During World War II Italy lost its entire colonial domain. Ethiopia was restored as an independent empire, and the other colonies eventually came under UN jurisdiction, in the first step toward decolonization in the African continent.

DECOLONIZATION FROM 1945

In the first postwar years there were some prospects that (except in the case of the Indian subcontinent) decolonization might come gradually and on terms favourable to the continued world power positions of the western European colonial nations. After the French defeat at Dien Bien Phu (Vietnam) in 1954 and the abortive Anglo-French Suez expedition of 1956, however, decolonization took on an irresistible momentum, so that by the mid-1970s only scattered vestiges of Europe's colonial territories remained.

The reasons for this accelerated decolonization were threefold. First, the two postwar superpowers, the United States and the Soviet Union, preferred to exert their might by indirect means of penetration—ideological, economic, and military—often supplanting previous colonial rulers; both the United States and the Soviet Union took up positions opposed to colonialism. Second, the mass revolutionary movements of the colonial world fought colonial wars that were expensive and bloody. Third, the war-weary public of western Europe eventually refused any further sacrifices to maintain overseas colonies.

In general, those colonies that offered neither concentrated resources nor strategic advantages and that harboured no European settlers won easy separation from their overlords. Armed struggle against colonialism centred in a few areas, which mark the real milestones in the history of postwar decolonization.

British decolonization, 1945–56. General elections in India in 1946 strengthened the Muslim League. In subsequent negotiations, punctuated by mass violence, the Congress Party leaders finally accepted partition as preferable to civil war, and in 1947 the British evacuated the subcontinent, leaving India and a territorially divided Pakistan to contend with problems of communal strife.

End of the Palestine mandate

Far more damaging to Britain's world position as a great power was the end of the Palestine mandate. The British would have favoured an Arab state in Palestine, tied to the British system in the Middle East, with Jews as a permanent minority. The Jewish national movement, however, succeeded in making this policy both costly and unpopular; in particular, the U.S. and Soviet governments began to see a Jewish state in Palestine as a necessary solution to the problem of Europe's surviving Jewry. All Arab spokesmen expressed intransigent opposition to any two-nation solution. Britain, isolated internationally, threw the problem into the lap of the United Nations; in November 1947 the General Assembly voted for partition. Britain, exhausted both politically and financially, decided to leave by May 15, 1948. The Jewish national movement's military branch succeeded in defeating the Palestine Arab terrorist and guerrilla bands step by step, and after British evacuation, and the declaration of Israel's independence, the Arab states in turn suffered a series of military defeats. The new Jewish state, recognized by the United States, the Soviet Union, and France, reached an uneasy armistice with the Arabs in 1949, and Britain's position in the Middle East began to crumble.

The Arab chain reaction against Britain started in Egypt, where in July 1952 a group of army officers seized power. By the end of 1954, Gamal Abdel Nasser had induced Britain to accept total withdrawal by June 1956 and set to work to undermine Britain's position in Iraq and Jordan. In June 1956 the British troops quit Suez on schedule. At that point Britain's Middle Eastern position, which depended on a chain of bases and friendly governments, was imperilled. Iran had moved close to the United States, warding off Soviet penetration and expropriating British oil holdings. Now Cyprus and the Persian Gulf oil ports remained the last outposts under British control in the Middle East. Nasser's next move was to cut the link between them. On July 26, 1956, he nationalized the Suez Canal Company, ending the last vestiges of European authority over that vital waterway and precipitating the most serious international crisis of the postwar era.

Wars in overseas France, 1945–56. The constitution of the French Fourth Republic provided for token decentralization of colonial rule, and cycles of revolt and repression marked French history for 15 years after the end of World War II. The first colonial war was in Indochina, where a power vacuum, caused by Japan's removal after wartime occupation, gave a unique opportunity to the Communist Viet Minh. When in 1946 the French Army tried to regain the colony, the Communists, proclaiming a republic, resorted to the political and military strategies of Mao Tse-tung to wear down and eventually defeat France. All chances for maintaining a semicolonial administration in Indochina ended when the Communists won the civil war in China (1949). Eventually, in 1954, when the French engaged the Communist armies in a pitched battle at Dien Bien Phu, the Communists won with the help of new heavy guns supplied by the Chinese. The Fourth Republic left Indochina under the terms of the Geneva Accords (1954), which set up two independent regimes.

Indochina War

By 1954 French North Africa was beginning to stir; guerrilla warfare occurred in both Morocco (where the French had deposed and exiled Sultan Muḥammad V) and Tunisia. On November 1, 1954, Algerian rebels began a revolt against France in which for the first time urban Muslims and Muslim peasants joined forces. In March 1956 France accorded complete independence to Morocco and Tunisia, while the army concentrated on a "revolutionary" counterinsurgent war in order to hold Algeria, where French rule had solid local support from about a million European settlers. The Muslim rebels depended on help from the Arab world, especially Egypt. Hence the French took the initiative, in October 1956, in forming an alliance with Nasser's principal adversaries, Britain and Israel, to reclaim the Suez Canal for the West and overthrow the pan-Arab regime in Cairo.

The Sinai–Suez campaign (October–November 1956). On October 29, 1956, Israel's army attacked Egypt in the Sinai Peninsula, and within 48 hours the British and French were fighting Egypt for control of the Suez area. But the Western allies found Egyptian resistance more determined than they had anticipated. Before they could turn their invasion into a real occupation, U.S. and Soviet pressure forced them to desist (November 7). The Suez campaign was thus a political disaster for the two colonial powers. The events of November 1956 showed the decline of European colonialism to be irreversible.

Algeria and French decolonization, from 1956. Between 1956 and 1958 French army commanders in Algeria, politically radicalized, tried to promote a new Franco-Muslim society in preparation for Algeria's total integration into France. Hundreds of thousands of rural Muslims were resettled under French military control, Algiers was successfully cleared of all guerrilla cells, French investments in Saharan petroleum grew, and, in a dramatic climax, a coalition of European settlers, colonial troops, and armed forces commanders in May 1958 refused further obedience to the Fourth Republic.

Charles de Gaulle, first president of the Fifth Republic,

thought that the effort of fighting colonial wars had prevented France from developing nuclear weapons and also came to realize that Algerian Muslims could not be converted to a French identity. He began to negotiate with the rebels; the negotiations culminated in a plebiscite, French evacuation, and proclamation of the independence of Muslim Algeria (July 1962). De Gaulle then proceeded to develop a nuclear striking force as the new foundation of France's status as a great power. The Fifth Republic moved rapidly toward freeing the colonies of sub-Saharan Africa, and France's colonial realm became vestigial and insular.

De Gaulle and decolonization

British decolonization after 1956. During the 15 years after the Suez disaster, Britain divested itself of most colonial holdings and abandoned most power positions in Africa and Asia. In 1958 the pro-British monarchy in Iraq fell; during the 1960s Cyprus and Malta became independent; and in 1971 Britain left the Persian Gulf. Of the imperial lifelines, only Gibraltar remains. After 1956 Britain moved rapidly to grant independence to its black African colonies. One British colony, Southern Rhodesia (now Zimbabwe), broke away unilaterally in 1965.

In Malaya the British fought a successful counterinsurgent war against a predominantly Chinese guerrilla movement and then turned over sovereignty to a federal Malaysian government (1957). In 1971 the Royal Navy left Singapore (an independent state since 1965), thus ending British presence in the Far East except at Hong Kong and (until 1983) at Brunei.

Britain's world position shrank, in effect, to membership in the North Atlantic Treaty Organization and the European Economic Community, with the postcolonial Commonwealth decreasing in importance.

Dutch, Belgian, and Portuguese decolonization. After World War II the Dutch tried to regain some of their lost control in Indonesia. The Sukarno regime held fast through three years of intermittent war, however, and the Dutch found no allies and no international support. In 1950 Indonesia became a centralized, independent republic.

The Belgian administration in the Congo had never trained even a small number of Africans much beyond the grade-school level. When Britain and France began to divest themselves of their colonies, Belgium was in no position to impose on the Congo a schedule of its own for gradual withdrawal. The abrupt granting of independence to the Belgian Congo in the summer of 1960 led to a series of civil wars, with intervention by the UN, European business interests employing white mercenaries, and other outside forces. In 1965 Joseph Mobutu (later Mobutu Sese Seko) gained control over the central government and created an independent African state, renamed Zaire in 1971.

The Belgian Congo

Portugal, in the 20th century the poorest and least developed of the western European powers, was the first nation (with Spain) to establish itself as a colonial power and the last to give up its colonial possessions. In Portuguese Africa during the authoritarian regime of António de Oliveira Salazar, the settler population had grown to about 400,000. After 1961 pan-African pressures grew, and Portugal found itself mired in a series of colonial wars, while the development of mining in Angola and Mozambique revealed hitherto unknown economic assets. In 1974 the armed forces overthrew the successors to Salazar, and in the unstable political situation it became clear that Portugal would cut its colonial ties to Africa. Portuguese Guinea (Guinea-Bissau) became independent in 1974. In June 1975 Mozambique achieved independence as a people's republic; in July 1975 São Tomé and Príncipe became an independent republic; and in November of the same year Angola, involved in a civil war between three rival liberation movements, also received sovereignty.

Conclusion. Historians will long debate the heritage of economic development, mass bitterness, and cultural cleavage that colonialism has left to the world, but the political problems of decolonization are grave and immediate. The international community is laden with minute states unable to secure either sovereignty or solvency and with large states erected without a common ethnic base. The world's postcolonial areas often have been scenes of protracted and violent conflicts: ethnic, as in Nigeria's Biafran war (1967–70); national-religious, as in the Arab-Israeli conflicts, the civil wars in Cyprus, and the clashes between India and Pakistan; or purely political, as in the confrontation between Communist and Nationalist regimes in the divided Korean Peninsula. The end of colonialism did not bring with it the spread of new, neatly divided nation-states throughout the world, nor did it abate or ease rivalry between the great powers.

Post-colonial conflict

(R.A.We.)

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(J.B.Mi./C.E.No./Ha.Ma./Ed.)

Ancient European Religions

For roughly 20,000 years, from the Upper Paleolithic period to the beginning of the Bronze Age (*c.* 3000 BC), the continent of Europe was home to a matrifocal, pre-agrarian culture, sedentary and peaceful, extending from the eastern shores of the Black and Mediterranean seas to the Aegean and Adriatic seas. To denote this period prior to the 3rd millennium BC, by which time Indo-European invaders from the steppe region north of the Black Sea had imposed their language and their patriarchal, violent culture across the continent, archaeologists use the term "Old Europe." (The term has also been used to describe a late phase in the development of Indo-European languages.)

According to archaeological evidence, the Old Europeans worshiped a goddess represented either as a corpulent woman similar to the Paleolithic "Venus" or as a waterbird or snake-woman. The latter type, having an elongated neck and prominent buttocks, sometimes strikingly suggests the form of a phallus. An incomplete list of the goddess' companions would include the bear, the bee, the bull, the deer, the dog, the hare, the hedgehog, the he-goat, the turtle, and the toad (the last associated with the iconography of the goddess in childbirth). After the Indo-European invasions, which began in about the mid-5th millennium BC and continued for some 2,000 years, the goddess cult survived in ancient Greece and western Anatolia in the worship of such deities as Hecate, Artemis, and Kubaba. There is no consensus of interpretation among scholars regarding the iconography of the goddess, yet her absolute predominance over male representations is unmistakable. Some scholars believe that the builders of such western European megalithic monuments as Stonehenge in southwestern England, whose chronology roughly coincides with that of Old Europe, were also goddess worshipers.

Scholars have long hypothesized an underlying relationship among ancient Western languages. In 1786, in his presidential address to the Royal Asiatic Society of Bengal, the British Orientalist Sir William Jones postulated the common ancestry of Latin, Greek, and Sanskrit. The first linguist to undertake the study of this relationship was the German Franz Bopp in the 19th century. Thomas Young, the 19th-century physician and Egyptologist who helped decipher the Rosetta Stone, in 1814 coined the term "Indo-European" to encompass the ancient languages Sanskrit, Old Iranian, Hittite, Greek, and Latin, together with the Slavic, Romance, Germanic, and Celtic language groups of modern Europe. In 1819 the German philosopher Friedrich von Schlegel adopted the word "Aryan" (which properly is the name of a people who in prehistoric times settled in what is now Iran and northern India) to designate the newly discovered "race"; four years later the German Orientalist Heinrich Julius Klaproth invented the term "Indo-German," which is no more legitimate than "Indo-Slav" or "Indo-Roman," but which was adopted out of national pride. Although 19th-century philologists took quite seriously the reconstruction of the Proto-Indo-European language—which was supposed to be the common ancestor of all Indo-European languages—to the point that they conducted correspondence with one another in this artificial idiom, it has remained debatable whether or not actual linguistic unity ever existed among Indo-European peoples.

As to the existence of a Proto-Indo-European homeland, the difficult interpretation of linguistic and archaeological data has led to a proliferation of theories, most of which, however, overlap. The American archaeologist Marija Gimbutas devised the theory of the Kurgan (Turkic and Russian: "barrow," or "artificial mound") culture of seminomadic Proto-Indo-European herdsmen whose original territory encompassed the lower Volga River basin. According to Gimbutas, these patriarchal pastoralists worshiped celestial and warlike gods associated with horses, cattle, and weapons.

About 4500 BC, these people embarked on a series of broad waves of expansion, and after the second wave (*c.* 3500 BC) a secondary homeland was established in the Danube River basin, roughly coinciding with what many linguists consider to be the Proto-Indo-European homeland. Although this designation has often been restricted to the Balkan Peninsula and the northern coast of the Black Sea, it can be said to extend from southern Scandinavia to the Balkans and from the Black Sea to the Rhine River, a region that also corresponds with the diffusion of so-called corded-ware pottery. The main linguistic argument for this larger designation is based on what scholars call "macrohydronymy," *i.e.*, the names of rivers longer than 300 miles (500 kilometres) within the above-mentioned territory. Twenty-six such rivers have Indo-European names derived from roots meaning "water," "river," "marsh," and the like; and the first non-Indo-European hydronyms are Kama and Ural in the east and Liger (Loire) and Garumna (Garonne) in the west.

Thus, in the period between *c.* 3500 and *c.* 2500 BC the Indo-European languages became distributed in Europe over an area stretching from the Alps and the Rhine River in the west to the Don River in the east, and from the North and Baltic seas and the Western Dvina River in the north to the Balkan Peninsula and western Asia Minor (Anatolia) in the south.

In the late 20th century some scholars have used linguistic evidence (including hydronymy) to propose that the original homeland of the Indo-Europeans was in the Middle East and encompassed eastern Anatolia, the southern Caucasus region, and northern Mesopotamia. While this theory gained only a few adherents, it did point up the exceedingly complex and problematic nature of any such model.

If the description, or even the existence, of a common language and a common homeland of most Bronze Age Europeans (1600–1200 BC; the main exception being the Finns, a non-Indo-European, Uralic people) is open to question, all the more so does their religion elude reconstruction. Common religious themes and structures among Indo-European peoples have been emphasized since the emergence of comparative mythology in the mid-19th century. The French philologist Georges Dumézil in the mid-20th century proposed a tripartite model of Indo-European society, encompassing three groups distinguished by "social function": priests, warriors, and producers. Influenced by the French sociologist Émile Durkheim (1858–1917), who defined religion as a system of symbols encoding the rules of society, Dumézil envisioned an Indo-European religion reflecting the tripartite social order. This model, for which he found striking evidence in the major Indo-European pantheons, remained the principal focus of his work for almost 50 years. In the classic summary of his position (1958), Dumézil explicitly stated that only Indo-European societies exhibited tripartition and that its occurrence in other societies indicates Indo-European influence. Obviously, this assertion weakens his argument, but his structural scheme has opened new perspectives in the search for a common foundation among Indo-European religions. (I.P.C.)

This article treats the beliefs in and organized worship and service of gods or other supernatural powers by the various cultural groups that flourished on the continent of Europe before or concurrently with the advent of the Christian religion. For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 822, and the *Index*.

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Celtic religion

The Celts, an ancient Indo-European people, reached the apogee of their influence and territorial expansion during the 4th century BC, extending across the length of Europe from Britain to Asia Minor. From the 3rd century BC onward their history is one of decline and disintegration, and with Julius Caesar's conquest of Gaul (58–51 BC) Celtic independence came to an end on the European continent. In Britain and Ireland this decline moved more slowly, but traditional culture was gradually eroded through the pressures of political subjugation; today the Celtic languages are spoken only on the western periphery of Europe, in restricted areas of Ireland, Scotland, Wales, and Brittany (in this last instance largely as a result of immigration from Britain from the 4th to the 7th century AD). It is not surprising, therefore, that the unsettled and uneven history of the Celts has affected the documentation of their culture and religion.

SOURCES

Problems of interpretation

Two main types of sources provide information on Celtic religion: the sculptural monuments associated with the Celts of continental Europe and of Roman Britain, and the insular Celtic literatures that have survived in writing from medieval times. Both pose problems of interpretation. Most of the monuments, and their accompanying inscriptions, belong to the Roman period and reflect a considerable degree of syncretism between Celtic and Roman gods; even where figures and motifs appear to derive from pre-Roman tradition, they are difficult to interpret in the absence of a preserved literature on mythology. Only after the lapse of many centuries—beginning in the 7th century in Ireland, even later in Wales—was the mythological tradition consigned to writing, but by then Ireland and Wales had been Christianized and the scribes and redactors were monastic scholars. The resulting literature is abundant and varied, but it is much removed in both time and location from its epigraphic and iconographic correlatives on the

Continent and inevitably reflects the redactors' selectivity and something of their Christian learning. Given these circumstances it is remarkable that there are so many points of agreement between the insular literatures and the continental evidence. This is particularly notable in the case of the Classical commentators from Poseidonius (*c.* 135–*c.* 51 BC) onward who recorded their own or others' observations on the Celts.

THE CELTIC GODS

The locus classicus for the Celtic gods of Gaul is the passage in Caesar's *Commentarii de bello Gallico* (52–51 BC; *The Gallic War*) in which he names five of them together with their functions. Mercury was the most honoured of all the gods and many images of him were to be found. Mercury was regarded as the inventor of all the arts, the patron of travelers and of merchants, and the most powerful god in matters of commerce and gain. After him the Gauls honoured Apollo, Mars, Jupiter, and Minerva. Of these gods they held almost the same opinions as other peoples did: Apollo drives away diseases, Minerva promotes handicrafts, Jupiter rules the heavens, and Mars controls wars.

In characteristic Roman fashion, however, Caesar does not refer to these figures by their native names but by the names of the Roman gods with which he equated them, a procedure that greatly complicates the task of identifying his Gaulish deities with their counterparts in the insular literatures. He also presents a neat schematic equation of god and function that is quite foreign to the vernacular literary testimony. Yet, given its limitations, his brief catalog is a valuable and essentially accurate witness. In comparing his account with the vernacular literatures, or even with the continental iconography, it is well to recall their disparate contexts and motivations. As has been noted, Caesar's commentary and the iconography refer to quite different stages in the history of Gaulish religion; the iconography of the Roman period belongs to an environment of profound cultural and political change, and the religion it represents may in fact have been less clearly structured than that maintained by the druids (the priestly order) in the time of Gaulish independence. On the other hand, the lack of structure is sometimes more apparent than real. It has, for instance, been noted that of the several hundred names containing a Celtic element attested in Gaul the majority occur only once, which has led some scholars to conclude that the Celtic gods and their cults were local and tribal rather than national. Supporters of this view cite Lucan's mention of a god Teutates, which they interpret as "god of the tribe" (it is thought that *teutā* meant "tribe" in Celtic). The seeming multiplicity of deity names may, however, be explained otherwise—for example, many are simply epithets applied to major deities by widely extended cults. The notion of the Celtic pantheon as merely a proliferation of local gods is contradicted by the several well-attested deities whose cults were observed virtually throughout the areas of Celtic settlement.

According to Caesar the god most honoured by the Gauls was "Mercury," and this is confirmed by numerous images and inscriptions. His Celtic name is not explicitly stated, but it is clearly implied in the place-name Lugudunon ("the fort or dwelling of the god Lugus") by which his numerous cult centres were known and from which the modern Lyon, Laon, and Loudun in France, Leiden in The Netherlands, and Legnica in Poland derive. The Irish and Welsh cognates of Lugus are Lugh and Lleu, respectively, and the traditions concerning these figures mesh neatly with those of the Gaulish god. Caesar's description of the latter as "the inventor of all the arts" might almost have been a paraphrase of Lugh's conventional epithet *sam ildánach* ("possessed of many talents"). An episode in the Irish tale of the Battle of Magh Tuiredh is a dramatic exposition of Lugh's claim to be master of all the arts and crafts, and dedicatory inscriptions in Spain and Switzerland, one of them from a guild of shoemakers, commemorate Lugus, or Lugoves, the plural perhaps referring to the god conceived in triple form. An episode in the Middle Welsh collection of tales called the *Mabinogion*, (or *Mabinogi*), seems to echo the connection with shoemaking, for it represents Lleu as working briefly as a skilled exponent of the craft. In Ireland Lugh was the youthful victor over the demonic Balar "of the venomous eye." He was the divine exemplar of sacral kingship, and his other common epithet, *lámhfhada* ("of the long arm"), perpetuates an old Indo-European metaphor for a great king extending his rule and sovereignty far afield. His proper festival, called Lughnasadh ("Festival of Lugh") in Ireland, was celebrated—and still is at several locations—in August; at least two of the early festival sites, Carmun and Tailtiu, were the reputed burial places of goddesses associated with the fertility of the earth (as was, evidently, the consort Maia—or Rosmerta ["the Provider"]—who accompanies "Mercury" on many Gaulish monuments).

The god Lugus

The Gaulish god "Mars" illustrates vividly the difficulty of equating individual Roman and Celtic deities. A famous passage in Lucan's *Bellum civile* mentions the bloody sacrifices offered to the three Celtic gods Teutates, Esus, and Taranis; of two later commentators on Lucan's text, one identifies Teutates with Mercury, the other with Mars. The probable explanation of this apparent confusion, which is paralleled elsewhere, is that the Celtic gods are not rigidly compartmentalized in terms of function. Thus "Mercury" as the god of sovereignty may function as a warrior, while "Mars" may function as protector of the tribe, so that either one may plausibly be equated with Teutates.

The problem of identification is still more pronounced in the case of the Gaulish "Apollo," for some of his 15 or more epithets may refer to separate deities. The solar connotations of Belenus (from Celtic: *bel*, "shining" or "brilliant") would have supported the identification with the Greco-Roman Apollo. Several of his epithets, such as Grannus and Borvo (which are associated etymologically with the notions of "boiling" and "heat," respectively), connect him with healing and especially with the therapeutic powers of thermal and other springs, an area of religious belief that retained much of its ancient vigour in Celtic lands throughout the Middle Ages and even to the present time. Maponos ("Divine Son" or "Divine Youth") is attested in Gaul but occurs mainly in northern Britain. He appears in medieval Welsh literature as Mabon, son of Modron (that is, of Matrona, "Divine Mother"), and he evidently figured in a myth of the infant god carried off from his mother when three nights old. His name survives in Arthurian romance under the forms Mabon, Mabuz, and Mabonagrain. His Irish equivalent was Mac ind Óg ("Young Son" or "Young Lad"), known also as Oenghus, who dwelt in Bruigh na Bóinne, the great Neolithic, and therefore pre-Celtic, passage grave of Newgrange (or Newgrange House). He was the son of Dagda (or Daghda), chief god of the Irish, and of Boann, the personified sacred river of Irish tradition. In the literature the Divine Son tends to figure in the role of trickster and lover.

The "Divine Son"

There are dedications to "Minerva" in Britain and throughout the Celtic areas of the Continent. At Bath she was identified with the goddess Sulis, whose cult there centred on the thermal springs. Through the plural form Suleviae, found at Bath and elsewhere, she is also related to the numerous and important mother goddesses—who often occur in duplicate or, more commonly, triadic form. Her nearest equivalent in insular tradition is the Irish goddess Brighid, daughter of the chief god, Dagda. Like Minerva she was concerned with healing and craftsmanship, but she was also the patron of poetry and traditional learning. Her name is cognate with that of Brigantī, Latin Brigantia, tutelary goddess of the Brigantes of Britain, and there is some onomastic evidence that her cult was known on the Continent, whence the Brigantes had migrated.

The Gaulish Sucellos (or Sucellus), possibly meaning "the Good Striker," appears on a number of reliefs and statuettes with a mallet as his attribute. He has been equated with the Irish Dagda, "the Good God," also called Eochaidh Ollathair ("Eochaidh the Great Father"), whose attributes are his club and his caldron of plenty. But, whereas Ireland had its god of the sea, Manannán mac Lir ("Manannán, son of the Ocean"), and a more shadowy predecessor called Tethra, there is no clear evidence for a Gaulish sea-god, perhaps because the original central European homeland of the Celts had been landlocked.

The "Great Father"

The insular literatures show that certain deities were associated with particular crafts. Caesar makes no mention of a Gaulish Vulcan, though insular sources reveal that there was one and that he enjoyed high status. His name in Irish, Goibhniu, and Welsh, Gofannon, derived from the Celtic word for smith. The weapons that Goibhniu forged with his fellow craft gods, the wright Luchta and the metalworker Creidhne, were unerringly accurate and lethal. He was also known for his power of healing, and as Gobbán the Wright, a popular or hypocoristic form of his name, he was renowned as a wondrous builder. Medieval Welsh also mentions Amaethon, evidently a god of agriculture, of whom little is known.

GODDESSES AND DIVINE CONSORTS

One notable feature of Celtic sculpture is the frequent conjunction of male deity and female consort, such as "Mercury" and Rosmerta, or Sucellos and Nantosvelta. Essentially these reflect the coupling of the protecting god of tribe or nation with the mother-goddess who ensured the fertility of the land. It is in fact impossible to distinguish clearly between the individual goddesses and these mother-goddesses, *matres* or *matronae,* who figure so frequently in Celtic iconography, often, as in Irish tradition, in triadic form. Both types of goddesses are concerned with fertility and with the seasonal cycle of nature, and, on the evidence of insular tradition, both drew much of their power from the old concept of a great goddess who, like the Indian Aditi, was mother of all the gods. Welsh and Irish tradition also bring out the multifaceted character of the goddess, who in her various epiphanies or avatars assumes quite different and sometimes wholly contrasting forms and personalities. She may be the embodiment of sovereignty, youthful and beautiful in union with her rightful king, or aged and hideously ugly when lacking a fitting mate. She may be the spirit of war, like the fearsome Morrígan or the Badhbh Chatha ("Raven of Battle"), whose name is attested in its Gaulish form, Cathubodua, in Haute-Savoie, or the lovely otherworld visitor who invites the chosen hero to accompany her to the land of eternal youth. As the life-giving force she is often identified with rivers, such as the Seine (Sequana) and the Marne (Matrona) in Gaul or the Boyne (Boann) in Ireland; many rivers were called simply Devona, "the Divine."

The goddess is the Celtic reflex of the primordial mother who creates life and fruitfulness through her union with the universal father-god. Welsh and Irish tradition preserve many variations on a basic triadic relationship of divine mother, father, and son. The goddess appears, for example, in Welsh as Modron (from Matrona, "Divine Mother") and Rhiannon ("Divine Queen") and in Irish as Boann and Macha. Her partner is represented by the Gaulish father-figure Sucellos, his Irish counterpart Dagda, and the Welsh Teyrnon ("Divine Lord"), and her son by the Welsh Mabon (from Maponos, "Divine Son") and Pryderi and the Irish Oenghus and Mac ind Óg, among others.

The "Divine Mother"

ZOOMORPHIC DEITIES

The rich abundance of animal imagery in Celto-Roman iconography, representing the deities in combinations of animal and human forms, finds frequent echoes in the insular literary tradition. Perhaps the most familiar instance is the deity, or deity type, known as Cernunnos, "Horned One" or "Peaked One," even though the name is attested only once, on a Paris relief. The interior relief of the Gundestrup Caldron, a 1st-century-BC vessel found in Denmark, provides a striking depiction of the antlered Cernunnos as "Lord of the Animals," seated in the yogic lotus position and accompanied by a ram-headed serpent; in this role he closely resembles the Hindu god Śiva in the guise of Paśupati, Lord of Beasts. Another prominent zoomorphic deity type is the divine bull, the Donn Cuailnge ("Brown Bull of Cooley"), which has a central role in the great Irish hero-tale *Táin Bó Cuailnge* ("The Cattle Raid of Cooley") and which recalls the Tarvos Trigaranus ("The Bull of the Three Cranes") pictured on reliefs from the cathedral at Trier, W.Ger., and at Nôtre-Dame de Paris and presumably the subject of a lost Gaulish narrative. Other animals that figure particularly prominently in association with the pantheon in Celto-Roman art as well as in insular literature are boars, dogs, bears, and horses. The horse, an instrument of Indo-European expansion, has always had a special place in the affections of the Celtic peoples. The goddess Epona, whose name, meaning "Divine Horse" or "Horse Goddess," epitomizes the religious dimension of this relationship, was a pan-Celtic deity, and her cult was adopted by the Roman cavalry and spread throughout much of Europe, even to Rome itself. She has insular analogues in the Welsh Rhiannon and in the Irish Édaín Echraidhe (*echraidhe,* "horse riding") and Macha, who outran the fastest steeds.

BELIEFS, PRACTICES, AND INSTITUTIONS

Cosmology and eschatology. Little is known about the religious beliefs of the Celts of Gaul. They believed in a life after death, for they buried food, weapons, and ornaments with the dead. The druids, the early Celtic priesthood, taught the doctrine of transmigration of souls and discussed the nature and power of the gods. The Irish believed in an otherworld, imagined sometimes as underground and sometimes as islands in the sea. The otherworld was variously called "the Land of the Living," "Delightful Plain," and "Land of the Young" and was believed to be a country where there was no sickness, old age, or death, where happiness lasted forever, and a hundred years was as one day. It was similar to the Elysium of the Greeks and may have belonged to ancient Indo-European tradition. In Celtic eschatology, as noted in Irish vision or voyage tales, a beautiful girl approaches the hero and sings to him of this happy land. He follows her, and they sail away in a boat of glass and are seen no more; or else he returns after a short time to find that all his companions are dead, for he has really been away for hundreds of years. Sometimes the hero sets out on a quest, and a magic mist descends upon him. He finds himself before a palace and enters to find a warrior and a beautiful girl who make him welcome. The warrior may be Manannán, or Lugh himself may be the one who receives him, and after strange adventures the hero returns successfully. These Irish tales, some of which date from the 8th century, are infused with the magic quality

Life after death

By courtesy of the Danish National Museum, Copenhagen



(Left) Gundestrup Caldron, from Gundestrup, Himmerland, Den., c. 1st century BC.
(Right) Interior of the caldron showing Cernunnos as "Lord of the Animals." In the Danish National Museum, Copenhagen.

that is found 400 years later in the Arthurian romances. Something of this quality is preserved, too, in the Welsh story of Branwen, daughter of Llŷr, which ends with the survivors of the great battle feasting in the presence of the severed head of Bran the Blessed, having forgotten all their suffering and sorrow. But this "delightful plain" was not accessible to all. Donn, god of the dead and ancestor of all the Irish, reigned over Tech Duinn, which was imagined as on or under Bull Island off the Beare Peninsula, and to him all men returned except the happy few.

Worship. According to Poseidonius and later classical authors Gaulish religion and culture were the concern of three professional classes—the druids, the bards, and between them an order closely associated with the druids that seems to have been best known by the Gaulish term *vates*, cognate with the Latin *vates* ("seers"). This threefold hierarchy had its reflex among the two main branches of Celts in Ireland and Wales but is best represented in early Irish tradition with its druids, *filidh* (singular *fili*), and bards; the *filidh* evidently correspond to the Gaulish *vates*.

The druids

The name druid means "knowing the oak tree" and may derive from druidic ritual, which seems in the early period to have been performed in the forest. Caesar stated that the druids avoided manual labour and paid no taxes, so that many were attracted by these privileges to join the order. They learned great numbers of verses by heart, and some studied for as long as 20 years; they thought it wrong to commit their learning to writing but used the Greek alphabet for other purposes.

As far as is known, the Celts had no temples before the Gallo-Roman period; their ceremonies took place in forest sanctuaries. In the Gallo-Roman period temples were erected, and many of them have been discovered by archaeologists in Britain as well as in Gaul.

Human sacrifice was practiced in Gaul: Cicero, Caesar, Suetonius, and Lucan all refer to it, and Pliny the Elder says that it occurred in Britain, too. It was forbidden under Tiberius and Claudius. There is some evidence that human sacrifice was known in Ireland and was forbidden by St. Patrick.

Festivals. Insular sources provide important information about Celtic religious festivals. In Ireland the year was divided into two periods of six months by the feasts

Beltine and Samhain

of Beltine (May 1) and Samhain (Samain; November 1), and each of these periods was equally divided by the feasts of Imbolc (February 1), and Lughnasadh (August 1). Samhain seems originally to have meant "summer," but by the early Irish period it had come to mark summer's end. Beltine is also called Cetšamain ("First Samhain"). Imbolc has been compared by the French scholar Joseph Vendryes to the Roman lustrations and apparently was a feast of purification for the farmers. It was sometimes called *oímelc* ("sheep milk") with reference to the lambing season. Beltine ("Fire of Bel") was the summer festival, and there is a tradition that on that day the druids drove cattle between two fires as a protection against disease. Lughnasadh was the feast of the god Lugh.

The impact of Christianity. The conversion to Christianity had inevitably a profound effect on this socio-religious system from the 5th century onward, though its character can only be extrapolated from documents of considerably later date. By the early 7th century the church had succeeded in relegating the druids to ignominious irrelevancy, while the *filidh*, masters of traditional learning, operated in easy harmony with their clerical counterparts, contriving at the same time to retain a considerable part of their pre-Christian tradition, social status, and privilege. But virtually all the vast corpus of early vernacular literature that has survived was written down in monastic scriptoria, and it is part of the task of modern scholarship to identify the relative roles of traditional continuity and ecclesiastical innovation as reflected in the written texts. Cormac's Glossary (*c.* 900) recounts that St. Patrick banished those mantic rites of the *filidh* that involved offerings to demons, and it seems probable that the church took particular pains to stamp out animal sacrifice and other rituals grossly repugnant to Christian teaching. What survived of ancient ritual practice tended to be related to *filidhecht*, the traditional repertoire of the *filidh*, or to the central institution of sacral kingship. A good example is the pervasive and persistent concept of the hierogamy (sacred marriage) of the king with the goddess of sovereignty: the sexual union, or *banais righi* ("wedding of kingship"), that constituted the core of the royal inauguration seems to have been purged from the ritual at an early date through ecclesiastical influence, but it remains at least implicit, and often quite explicit, for many centuries in the literary tradition. (M.D./P.Mac C.)

Germanic religion

Germanic religion comprises the mythology, religious beliefs, and cults of the Germanic-speaking peoples before their conversion to Christianity. Germanic culture extended, at various times, from the Black Sea to Greenland, or even the North American continent. Germanic religion played an important role in shaping the civilization of Europe. But since the Germanic peoples of the Continent and of England were converted to Christianity in comparatively early times, it is not surprising that less is known about the gods whom they used to worship and the forms of their religious cults than about those of Scandinavia, where Germanic religion survived until relatively late in the Middle Ages.

SOURCES

Classical and early medieval sources. The works of classical authors, written mostly in Latin and occasionally in Greek, throw some light on the religion of Germanic peoples; however, their interest in the religious practices of Germanic tribes remains limited to its direct relevance to their narrative, as when Strabo describes the gory sacrifice of Roman prisoners by the Cimbri at the end of the 2nd century BC.

For all his knowledge of the Celts, Caesar had no more than a superficial knowledge of Germans. He made some judicious observations in *Commentarii de bello Gallico* about their social and political organization, but his remarks on their religion were rather perfunctory. Contrasting Germans with the Celts of Gaul, Caesar claimed that the Germans had no druids (*i.e.*, organized priesthood), nor zeal for sacrifice, and counted as gods only the Sun, the fire god (Vulcan or *Vulcanus*), and the Moon. His limited information accounts for Caesar's assumption of the poverty of the Germanic religion and the partial inaccuracy and incompleteness of his statement.

Tacitus, on the contrary, provided a lucid picture of customs and religious practices of continental Germanic tribes in his *Germania*, written *c.* AD 98. He describes some of their rituals and occasionally names a god or goddess. While Tacitus presumably never visited Germany, his information was partly based on direct sources; he also used older works, now lost.

Early medieval records. As the power of Rome declined, records grew poorer, and nothing of great importance survives before the *Getica*, a history of the Goths written by the Gothic historian Jordanes *c.* 550; it was based on a larger (lost) work of Cassiodorus, which also incorporated the earlier work of Ablavius. The *Getica* incorporates valuable records of Gothic tradition, the origin of the Goths, and some important remarks about the gods whom the Goths worshipped and the forms of their sacrifices, human and otherwise.

Origin of the Lombards

A story about the origin of the Lombards is given in a tract, *Origo gentis Langobardorum* ("Origin of the Nation of Lombards"), of the late 7th century. It relates how the goddess Frea, wife of Godan (Wodan), tricked her husband into granting the Lombards victory over the Vandals. The story shows that the divine pair, recognizable from Scandinavian sources as Odin and Frigg, was known to the Lombards at this early time. A rather similar story about this pair is told in a Scandinavian source. The Lombard Paul the Deacon, working late in the 8th or early in the 9th century, repeated the tale just mentioned in his fairly comprehensive *Historia Langobardorum* ("History of the Lombards"). Paul used written sources available to him and seemed also to draw upon Lombard tradition in prose and verse.

The Venerable Bede, writing his *Historia ecclesiastica gentis Anglorum* ("Ecclesiastical History of the English People") early in the 8th century, showed much interest in the conversion of the English and some in their earlier religion. The lives of Irish and Anglo-Saxon missionaries who worked among Germanic peoples on the Continent (*e.g.,* Columbanus, Willibrord, and Boniface) provide some information about pagan customs and sacrifices.

The first detailed document touching upon the early religion of Scandinavia is the biography by St. Rembert (or Rimbert) of St. Ansgar (or Anskar), a 9th-century missionary and now patron saint of Scandinavia, who twice visited the royal seat, Björkö, in eastern Sweden, and noticed some religious practices, among them the worship of a dead king. Ansgar was well received by the Swedes, but it was much later that they adopted Christianity.

Some two centuries later, *c.* 1072, Adam of Bremen compiled his *Gesta Hammaburgensis ecclesiae pontificum* (*History of the Archbishops of Hamburg-Bremen*), which included a description of the lands in the north, then part of the ecclesiastical province of Hamburg. Adam's work is particularly rich in descriptions of the festivals and sacrifices of the Swedes, who were still largely pagan in his day.

German and English vernacular sources. Learned sources, such as those just mentioned, may be supplemented by a few written in vernacular in continental Germany and England. Among the most interesting are two charms, the so-called Merseburg Charms, found in a manuscript of *c.* 900, in alliterating verse. The charms appear to be of great antiquity, and the second, intended to cure sprains, contains the names of seven deities. Four of these are known from Scandinavian sources, *viz.,* Wodan (Odin), Friia (Frigg), Volla (Fulla), and Balder, but *balder* could merely designate the lord and apply to Wodan's companion Phol, an otherwise unidentified god. Sinthgunt (Sinhtgunt in the manuscript), the sister of Sunna ("Sun"), could be a name for the Moon.

A manuscript of the 9th century contains a baptismal vow in the Saxon dialect, probably dating from the 8th century. The postulant is made to renounce the Devil and all his works, as well as three gods, Thunaer (Donar/Thor), Wôden (Wodan/Odin), and Saxnôt, whose name has been associated with Seaxneat, who appears as the son of Wôden in the genealogy of the kings of Essex. Saxnôt is undoubtedly a Saxon tribal god, but it is not clear whether the second element of his name means "companion" or refers to "(sacrificial) cattle."

Old English sources

Vernacular sources in Old English are rich, but reveal little about the pre-Christian religion. The poem *Beowulf* is based upon heroic traditions, ultimately of Scandinavian origin, but in spite of its rather thorough Christianization, it retains a number of striking Germanic elements in its symbolism and contents. The fight of Beowulf against the monsters from the dark is paralleled by the struggle of Scandinavian heroes against trolls. The same heroism and defiance of death that characterize Germanic warrior ethics are found in minor historical poems, such as the *Battle of Brunanburh* and the *Battle of Maldon.* Old English literature also includes numerous charms intended as safeguards against illnesses and misfortunes, but these can hardly be called religious. In the 9th century *Runic Poem,* an old tradition about the god Ing has clearly been retained. Wôden (Odin) is also mentioned repeatedly in Old English sources; he is frequently named among ancestors of the royal houses.

Scandinavian literary sources. The greater part of scholarly knowledge of Germanic religion comes from literary sources written in Scandinavia. These sources are mostly written in the Old Norse language, and they are nearly all preserved in manuscripts written in Iceland from the 12th to 14th century or in later copies of manuscripts written at that period. This implies a surviving tradition and an antiquarian revival in that distant outpost of Scandinavian culture.

The oldest of the sources found in the Icelandic manuscripts are in verse. Although remembered and written down in Iceland, some of these verses originated elsewhere, some in Norway and a few in Denmark and Sweden. Some of them may well be older than the settlement of Iceland, which took place toward the end of the 9th century. The Icelanders remained pagan until the year 999 or 1000.

The Icelandic manuscripts are written either in Eddic or in skaldic verse. The Eddic poetry is mostly composed in free alliterative measures, much like that of the Old English *Beowulf.* Much of it is preserved in a manuscript now called the *Elder Edda,* or *Poetic Edda,* written in Iceland *c.* 1270 and containing material centuries older. The meaning of the name *Edda* is disputed; it was not originally applied to this book but to another mentioned below.

The *Elder Edda* consists of a number of lays, which may be divided into two classes, the mythological and the heroic. The mythological poems contain stories about the northern Germanic gods; words of wisdom; a cosmogony, depicting the beginning of the world; and an apocalyptic description of the Ragnarök, the end of the ancient Scandinavian world. There is much controversy among scholars about the date and place of origin of several of the lays preserved in the *Edda* and minor collections. The first lay is the "Völuspá" ("Prophecy of the Seeress") which, in about 65 short stanzas, covers the history of the world of gods from the beginning to the Ragnarök. In spite of its clearly pagan theme, the poem reveals Christian influence in its imagery. The scenery described is that of Iceland, and it is commonly thought that it was composed in Iceland about the year 1000, when Icelanders perceived the fall of their ancient gods and the approach of Christianity.

"Hávamál"

The "Hávamál" ("Words of the High One") is a heterogeneous collection of aphorisms, homely wisdom, and counsels, as well as magic charms, ascribed to Odin. It contains at least five separate sections, some of which definitely point to their origin in Norway in the Viking age (9th–10th century) by their scenery and view of life. Of interest are the myths about Odin's erotic affairs, illustrating his cynical remarks about man's relation to woman, especially his amorous adventure leading to the theft of the precious mead. Particularly important is the account of Odin's hanging himself on the world tree, Yggdrasill, a name apparently meaning "Odin's Horse."

In another poem Odin engages in a contest of wits with an immensely wise giant (Vafthrúdnir). The poem, in the form of question and answer, tells of the cosmos, gods, giants, the beginning of the world, and its end. The other lays of the first section of the *Elder Edda* deal essentially with the adventures of the gods, especially Thor's relations with the giants, such as when he goes fetching the brewing kettle, fishing for the Midgard-Serpent, and recovering his hammer Mjölnir. The "Lokasenna" ("The Flyting of Loki"), which sharply criticizes the behaviour of the major Scandinavian gods and goddesses, perhaps on the model of Lucian's *Assembly of the Gods,* is presumably a late addition, written *c.* 1200. Similarly, the political implications in the "Rígsthula" suggest that this poem about the divine origin of social stratification dates at least to the 13th century.

The second section of the *Elder Edda* tells of traditional Germanic heroes, such as Sigurd (Siegfried) or Völundr (Wayland the Smith). Many of the stories told there are also known from continental Germany and England, but the Norse sources preserve them in an older and purer form. They are of some interest for the study of religion because the gods often intervene in the lives of heroes.

The Icelandic and, to a lesser extent, the Norwegian manuscripts of the 13th and 14th centuries contain a great bulk of poetry of a quite different kind. This is commonly, if unjustifiably, called skaldic poetry. The skaldic verse forms were perhaps devised in Norway in the 9th century. They differ fundamentally from the traditional Germanic and Eddic forms in that the syllables are strictly counted and the lines must end in a given form. The skalds also used a complicated system of alliteration, as well as internal rhyme and consonance. With all these constraints, their short, eight-line strophes, falling neatly into four-line half strophes, are often difficult to understand because of the complexity of the syntax and of an abstruse diction, making a very extensive use of periphrastic metaphors called kennings. These phrases, *e.g.,* "Sif's hair" or "the

otter's ransom" for "gold," allude to specific myths, and their testimony is most reliable to assess pagan worship. Skaldic poetry is often composed in praise of chieftains of Norway and other Scandinavian lands. Its authors are frequently named, and their approximate date is known.

After the Icelanders were converted to Christianity, much of their ancient poetry survived this religious change, as did traditions about pagan gods and their worship. Icelanders of the 12th century traveled widely and were among the most lettered people in Europe, studying and translating homilies, saints' lives, and other learned literature of Europe. During the 13th century there was a revival of the Icelanders' interest in the practices of their pagan ancestors, as well as in those of their kinsfolk in Norway and, to a lesser extent, in Sweden.

The *Edda* and other writings of Snorri Sturluson

The name chiefly associated with this revival is that of Snorri Sturluson (1179–1241). Snorri acquired great wealth and received the best education available. He became a powerful man in Icelandic politics, and political intrigue led to his assassination in 1241. The first of Snorri's works and one of the most memorable was his *Prose Edda,* written *c.* 1220. It is to this book that the title *Edda,* whatever its meaning, originally belonged.

It is likely that Snorri wrote the various sections of this book in an order opposite to that which they now have. He began with a poem exemplifying 102 different forms of verse, addressed to Haakon, the young king of Norway, and his uncle Earl Skúli Baardson. He then furnished a section entitled "Skáldskaparmál" ("Poetic Diction"), explaining and illustrating the abstruse allusions to gods and ancient heroes in the poetry of the skalds. After this, he wrote an introduction to the mythology of the north in the "Gylfaginning" ("Beguiling of Gylfi"), a section describing all of the major gods and their functions. Snorri worked partly from Eddic and skaldic poetry still extant, but partly from sources that are now lost. He presents a clear, if not altogether reliable, account of the gods, the creation of the world, and Ragnarök.

Another important work ascribed to Snorri is the *Heimskringla* ("Orb of the World"), a history of the kings of Norway from the beginning to the mid-12th century. The first section of this book, the "Ynglinga saga," is of particular interest, for in it, Snorri described the descent of the kings of Norway from the royal house of Sweden, the Ynglingar, who, in their turn, were said to descend from gods. Snorri used such written sources as were available; he also relied on skaldic poems, some of which were very old. Snorri visited Norway twice and Sweden once, and he probably used popular traditions that he heard in both countries.

About the beginning of the 13th century Icelanders began to write so-called family sagas, or Icelanders' sagas; *i.e.,* lives of their ancestors who had settled in Iceland in the late 9th century, and lived through the 10th and 11th centuries. A good deal had already been written about these people in summary form by Ari the Learned (*c.* 1067–1148) and other scholars of the early 12th century, but much more had been preserved in tradition handed down in verse and prose.

The reliability of family sagas as sources of history has long been debated and no simple answer can be given. Each saga has to be studied separately, with a view not only to the author's sources but also to his aims. Some of the authors were antiquarians and tried to relate faithfully the history of a district, a family, or a hero; others simply entertained by writing historical fiction.

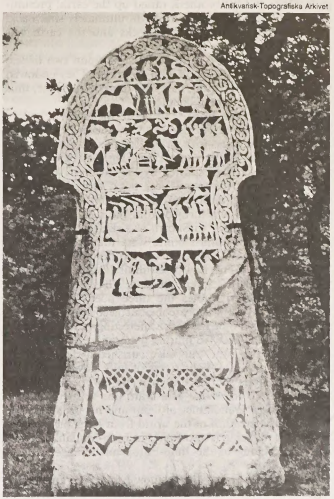
Saxo Grammaticus

About the time when the first family sagas were written, the Dane Saxo Grammaticus, secretary of Absalon, archbishop of Lund, was compiling in Latin his great history of the Danes (*Gesta Danorum*). The first nine books of this work deal with the prehistory of the Danes and are actually a history of the ancient gods and heroes. Interpreting the old religion euhemeristically (*i.e.,* by reducing the gods to the level of distinguished men), Saxo regarded the pagan gods chiefly as crafty men of old. Some of his sources may have been Danish traditions and poetry now lost, but he derived much of his information from vagrant Icelanders, of whom he speaks with some respect.

Material such as Saxo used was also used by Icelanders some generations later in the so-called heroic sagas (*Fornaldar Sögur*). Sagas of this kind describe the adventures of heroes who lived, or were supposed to have lived, in Scandinavia or on the Continent before Iceland was peopled. The gods, and particularly Odin, are frequently said to take part in the affairs of men, but since few of the heroic sagas were written before the 14th century, and the aim of their authors was often entertainment rather than instruction, these sagas can be used as sources only with utmost discrimination.

Other sources. *Archaeology.* The archaeological finds of Scandinavia are rich, and information about religious beliefs may be drawn especially from the grave goods and forms of burial. It may, in fact, be possible to trace continuity of belief from the Bronze Age to the Viking age in the 9th and 10th centuries. Archaeological finds, however, are difficult to interpret from a religious point of view. The numerous petroglyphs of southern Scandinavia, dating to the 2nd millennium BC, attest to an extensive sun cult and prevalent fertility rites. Other early Bronze Age finds such as the Trundholm chariot of the sun confirm these religious practices. Ship or boat graves were initially meant to carry the buried or cremated remains of those put in them to the otherworld, but such practices could later have become purely conventional.

Antikvarisk-Topografiska Arkivet



Memorial stone from Gotland, Sweden, showing battle scenes and ships. In the third panel from the top, a warrior is being hanged in a tree as a sacrifice to Odin, whose cult is represented by an eagle and a twisted knot. Late 8th century.

A number of small images in silver or bronze, dating from the Viking age, have also been found in various parts of Scandinavia. They show Thor with his hammer or a fertility god with full erection, perhaps Freyr; frequently found is a silver hammer, the symbol of Thor, often worn as an amulet, like the hundreds of gold medals or bracteates, representing Germanic deities worshiped on the Continent and in Scandinavia in the 5th–6th century.

Runic inscriptions. The runic alphabet was used throughout the Germanic world beginning in about the 1st century AD. The runes had magical and sacral significance. Occasionally one god or another is named; the god Thor may be called upon to hallow a grave.

Place-names. Theophoric place-names (derived from or

compounded with the name of a god) are found in all Germanic lands. Such names supplement the limited information available concerning pagan religion in Continental Germany and England. The theophoric place-names of Norway and Sweden are richer and have been carefully sifted. The evidence drawn from them must, however, be handled with caution. A name such as Thorslundr ("Thor's Grove") does not necessarily imply that Thor was worshiped there, for names are often transferred by settlers from one place to another, as from England to America and, in the Viking age, from the Scandinavian mainland to Iceland. Groups of theophoric place-names may, however, provide evidence of the cult of one god or another.

MYTHOLOGY

The beginning of the world of giants, gods, and men. The story of the beginning is told, with much variation, in three poems of the *Elder Edda,* and a synthesis of these is given by Snorri Sturluson in his *Prose Edda.* Snorri adds certain details that he must have taken from sources now lost.

"Völuspá"

Defective as it is, the account of the "Völuspá" appears to be the most rational description of the cosmogony. The story is told by an age-old seeress who was reared by primeval giants. In the beginning there was nothing but Ginnungagap, a void charged with magic force. Three gods, Odin and his brothers, raised up the earth, presumably from the sea into which it will ultimately sink back. The sun shone on the barren rocks and the earth was overgrown with green herbage.

Later, Odin and two other gods came upon two lifeless tree trunks, Askr and Embla, on the shore. They endowed them with breath, reason, hair, and fair countenance, thus creating the first human couple.

A quite different story is told in the didactic poem "Vafthrúdnismál" ("The Lay of Vafthrúdnir"). The poet ascribes his ancestry to a primal giant, Aurgelmir, who sometimes goes by the name Ymir. The giant grew out of the venom-cold drops spurted by the stormy rivers called Élivágar. One of the giant's legs begat a six-headed son with the other leg, and under his arms grew a maid and a youth. The earth was formed from the body of the giant Ymir who, according to Snorri, was slaughtered by Odin and his brothers. Ymir's bones were the rocks, his skull the sky, and his blood the sea. Another didactic poem, "Grímnismál" ("The Lay of Grímnir [Odin]"), adds further details. The trees were the giant's hair and his brains the clouds. Snorri quotes the three poetic sources just mentioned, giving a more coherent account and adding some details. One of the most interesting is the reference to the primeval cow Audhumla (Auðumla), formed from drops of melting rime. She was nourished by licking salty, rime-covered stones. Four rivers of milk flowed from her udders and thus she fed the giant Ymir. The cow licked the stones into the shape of a man; this was Buri (Búri), who was to be grandfather of Odin and his brothers. The theme of the creation of the world from parts of the body of a primeval being is also found in Indo-Iranian tradition and may belong to the Indo-European heritage in Germanic religion.

A central point in the cosmos is the evergreen ash, Yggdrasill, whose three roots stretch to the worlds of death, frost-giants, and men. A hart (stag) is biting its foliage, its trunk is rotting, and a cruel dragon is gnawing its roots. When Ragnarök approaches, the tree will shiver and, presumably, fall. Beneath the tree stands a well, the fount of wisdom. Odin got a drink from this well and had to leave one of his eyes as a pledge.

The gods. Old Norse sources name a great number of deities. The evidence of place-names suggests that one cult succeeded another. Names, especially those in southeastern Norway and southern Sweden, suggest that there was once widespread worship of a god Ull (Ullr). Indeed, an early poem reports an oath on the ring of Ull, suggesting that he was once one of the highest gods, at least in some areas. Beyond that, little is known about Ull; he was god of the bow and snowshoes, and, according to Saxo Grammaticus, who calls him Ollerus, he temporarily replaced Odin when the latter was banned from his throne.

The gods can be divided roughly into two tribes, Aesir and Vanir. At one time, according to fairly reliable sources, there was war between the Aesir and the Vanir, but when neither side could score a decisive victory they made peace and exchanged hostages. In this way, the specialized fertility gods, the Vanir, Njörd (Njörðr), his son Freyr, and presumably his daughter, Freyja, came to dwell among the Aesir and to be accepted in their hierarchy.

Two tribes of gods: Aesir and Vanir

Odin (Óðinn). According to literary sources, Odin was the foremost of the Aesir, but the limited occurrence of his name in place-names seems to indicate that his worship was not widespread. He appears, however, to have been the god of kings and nobility more than the deity to whom the common man would turn for support. His name defines him as the god of inspired mental activity and strong emotional stress, as it is related to Icelandic *óðr,* which applies to the movements of the mind, and to German *Wut,* meaning "rage," or "fury." This qualifies him as the god of poetic inspiration and the stories about the origin of poetry narrate how Odin brought the sacred mead of poetry to the world of the gods. This beverage was first brewed from the blood of a wise god, Kvasir, who was murdered by dwarfs. It later came into the hands of a giant and was stolen by Odin, who flew from the giant's stronghold in the shape of an eagle, carrying the sacred mead in his crop to regurgitate it in the dwelling of the gods. Therefore, the early skalds designate poetry as "Kvasir's blood" or "Odin's theft."

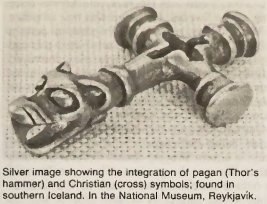
There is also a darker side to Odin's personality: he incites kinsmen to fight and turns against his own favourites, because he needs heroes in the otherworld to join him in the final battle against the forces of destruction at the time of Ragnarök. Therefore, the fallen warriors on the battlefield are said to go to his castle Valhalla (Valhöll), the "Hall of the Slain," where they live in bliss, training for the ultimate combat. He is also a necromancer and a powerful magician who can make hanged men talk. He is the god of the hanged, because he hanged himself on the cosmic tree Yggdrasill to acquire his occult wisdom. As the "Hávamál" tells us, he hung there for nine nights, pierced with a spear, sacrificed to himself, nearly dead, to gain the mastery of the runes and the knowledge of the magic spells that blunt a foe's weapons or free a friend from fetters.

Valhalla

Odin could change his shape at will, and, with his body in cataleptic sleep, he traveled to other worlds, like a shaman. As god of the dead, he was accompanied by carrion beasts, two wolves and two ravens. These birds kept him informed of what happened in the world, adding to the knowledge he had acquired by relinquishing his one eye in the well of Mímir under the tree Yggdrasill.

Untrustworthy, Odin may break the most sacred oath on the holy ring. As "spear-thruster," he opens the hostilities, and in the bellicose period of the Viking expeditions his cult appeared to gain momentum. Odin, like Wōden or Wotan, is, however, essentially the sovereign god, whom the Germanic dynasties, in England as well as in Scandinavia, originally regarded as their divine founder. He thus maintains the prominent position of Wōðan[az] in classical antiquity, to whom, according to Tacitus, human sacrifice was offered. Latin writers identified Wōðan[az] with Mercury, as the name of the day, Wednesday, (*i.e.,* "day of Wōden"), for *Mercurii dies* (French *mercredi*), indicates. It is possible that the tribal god of the Semnones, described by Tacitus as *regnator omnium deus* ("the god governing all"), could be identified with Wōðan[az]. They would indeed sacrifice a man to him in a sacred grove in what the ancient author describes as a "horrendous ritual."

Thor (þórr). Thor is a god of very different stamp. Place-names, personal names, poetry, and prose show that he was worshiped widely, especially toward the end of the pagan period. Thor is described as Odin's son, but his name derives from the Germanic term for "thunder." Like Indra and other Indo-European thunder-gods, he is essentially the champion of the gods, being constantly involved in struggles with the giants. His main weapon is a short-handled hammer, Mjölnir, with which he smashes the skull of his antagonists. One of his best-known adventures describes his pulling the cosmic serpent Jörmungand (Jörmungandr), which surrounds the world, out of the



Silver image showing the integration of pagan (Thor's hammer) and Christian (cross) symbols; found in southern Iceland. In the National Museum, Reykjavík.
By courtesy of the National Museum, Reykjavik. photograph, Gerd Gestsson

ocean. As he fails to kill the monster then, he will have to face it again in a combat to the finish in which they both die, in the Ragnarök.

Thor is the god of the common man. As place-names in eastern Scandinavia and in England indicate, peasants worshiped him because he brought the rains that ensured good crops. Warriors trusted him, and he seems to have been popular with them everywhere. He was well known as Thunor in the Saxon and Jutish areas in England; the Saxons on the mainland venerated him as Thunær. When the Vikings conquered Normandy and the Varangians settled in Russia, they called upon Thor to help them in their military enterprises.

On account of his association with thunder, the Germanic god *þunraz* (Thor) was equated with Jupiter by the Romans; hence, the name of the day, Thursday (German *Donnerstag*), for *Jovis dies* (Italian *giovedì*). Thor traveled in a chariot drawn by goats, and later evidence suggested that thunder was thought of as the sound of his chariot.

Balder (*Baldr*). The west Norse sources name another son of Odin, Balder, the immaculate, patient god. When Balder had dreams foreboding his death, his mother, Frigg, took oaths from all creatures, as well as from fire, water, metals, trees, stones, and illnesses, not to harm Balder. Only the mistletoe was thought too young and slender to take the oath. The guileful Loki tore up the mistletoe and, under his guidance, the blind god Höd (Höðr) hurled it as a shaft through Balder's body. The gods sent an emissary to Hel, goddess of death; she would release Balder if all things would weep for him. All did, except a giantess, who appears to be none other than Loki in disguise. There is another version of this story, to which allusion is made in a west Norse poem (*Baldrs draumar*). According to this Loki does not seem to be directly responsible for Balder's death but Höd alone. Balder's name occurs rarely in place-names, and it does not appear that his worship was widespread.

The Danish historian Saxo gives an entirely different picture of Balder: he is not the innocent figure of the west Norse sources but a vicious and lustful demigod. He and Höd were rivals for the hand of Nanna, said in west Norse sources to be Balder's wife. After many adventures, Höd pierced Balder with a sword. In order to secure vengeance, Odin raped a princess, Rinda (Rindr), who bore a son, Bous, who killed Höd.

Saxo's story has many details in common with the west Norse sources, but his views of Balder were so different that he may have been following a Danish rather than a west Norse tradition. Much of Saxo's story is placed in Denmark.

There has been much dispute among scholars about the symbolic significance of Balder's myth. He has been described as a dying spring god; some have stressed his Christ-like features in the west Norse version. The major protagonists in the drama have warrior names, and the game in which the gods hurl missiles at the almost invulnerable Balder is reminiscent of an initiatory test.

Loki. There is no more baffling figure in Norse mythology than Loki. He is counted among the Aesir but is not one of them. His father was a giant (Fárbauti; "Dangerous Striker"). Loki begat a female, Angrboða (Angrboða; "Boder of Sorrow"), and produced three evil progeny—the goddess of death, Hel, the monstrous serpent surrounding the world, Jörmungand, and the wolf Fenrir (Fenrisúlfr), who lies chained until he will break loose in the Ragnarök. Loki himself lies bound but will break his bonds in the Ragnarök to join the giants in battle against the gods.

Loki deceived the gods and cheated them, but sometimes he got them out of trouble. He is seen in company with Odin and an obscure god Hœnir, and he is called the friend of Thor. He is essentially a "trickster" figure who can change sex and shape at will. Thus, he can give birth as well as beget offspring. The eight-legged horse of Odin, Sleipnir, was born of Loki in the shape of a mare. According to an Eddic lay, Loki ate the heart of an evil woman and grew pregnant. He fights with Heimdall in the shape of a seal for the possession of the Brísingamen necklace, and later, he sneaks into Freyja's residence in the form of a fly to steal the same precious object for Odin. According to an early poem, Odin and Loki had mixed their blood as foster brothers. It has been suggested that Loki was a hypostasis of Odin, or at least that he represents Odin's darkest side. He seems to symbolize "impulsive intelligence," together with an irrepressible urge to act and an unpredictable maliciousness. Origin of monsters

Minor Aesir. A number of minor deities are also ranked among the Aesir. The god Heimdall (Heimdal[l]r) is particularly interesting, but rather enigmatic. His antagonism with Loki, with whom he struggles for the possession of the Brísingamen necklace, results in their killing each other in the Ragnarök, according to Snorri. Heimdall is of mysterious origin: he is the son of nine mothers, said to be sisters, all of whom bear names of giantesses, though they are mostly identified with the storm waves. Heimdall lives in Himinbjörg ("Heavenly Fells"), at the edge of the world of the Aesir, which he guards against the giants. He is endowed with a wonderful hearing, detecting anything in the world, but he is blamed with drinking too much mead. When the Ragnarök draws near, he will blow his ringing horn (Gjallarhorn).

Another myth in which he appears as Rigr (Rígr), a name probably derived from the Irish *rí* ("king"), makes Heimdall the father of mankind. He consorted with three women, from whom descend the three classes of men—serf (*hrall*), freeman (*karl*), and nobleman (*jarl*).

Information about the Scandinavian gods is based chiefly on poetry composed late in the pagan period and on the remarks of outside observers, who generally had little interest in what they considered to be heathendom. Many gods were nearly forgotten when these authors mentioned them, as is the case with Ull, described above. Similarly, memories had apparently faded about Tyr (Týr), who must have been a major god in early times. His name, derived from Germanic *Twaz* (Old English *Tiw*) and related to the Greek god Zeus, suggests that he was originally a sky-god, but in Roman times, he was equated with Mars, and hence *dies Martis* (Mars's day; French *mardi*) became Tuesday (Icelandic *Týs dagr*). Tyr is the one-handed god, because one of his hands had been bitten off by the wolf Fenrir. He is brave and warlike; in the Ragnarök he will face the hellhound Garm (Garmr), and they will kill each other. Like other gods, Tyr is said to be a son of Odin, but, according to one early poem, he was the son of a giant. Tyr's cult is remembered in place-names, particularly those of Denmark.

Bragi. Bragi appears in later sources as the god of poetry and eloquence. It is remarkable that the first recorded skald, living in the 9th century, was also called Bragi. Since there is no record of a cult of the god Bragi, some have suspected that the god and the poet are identical.

Frigg. Frigg is the wife of Odin. In the southern Germanic sources she appears as Fria (Second Merseburg Charm) or Frea (Langobardic), the spouse of Wodan. Snorri depicted her as the weeping mother of Balder, but Saxo described her as unchaste and makes her misconduct responsible for the temporary banishment of Odin. In the "Ynglinga saga," Odin's brothers Vili and Vé share her during his absence in a polyandric relationship similar to that of Draupadī in Hindu myth. She has been equated with Venus, and her name survives in Friday (Old English *Frigedæg*) from *dies Veneris*, Venus' day.

Idun (*Iðunn*). According to an early skaldic poem (*c.*

900), Idun, the wife of Bragi, was entrusted with the apples that prevent the gods from growing old. She was abducted by the giant Thjazi, but Loki brought her back with the precious apples. This myth has many parallels such as Heracles' obtaining the golden apples of the Hesperides.

Jörd (Jörðr). The name Jörd means "earth," but this goddess who is described as the mother of Thor, and consequently Odin's lover, is also known under different names, such as Fjörgyn ("Earth"), perhaps originally a goddess of the furrow, and Hlödyn (Hlöðyn). A *dea Hludana* is also remembered in votive inscriptions of lower Germany and Holland.

The Vanir. The Vanir represent a distinct group of gods associated with wealth, health, and fertility. Although they would also fight, the Vanir were not essentially gods of battle, like the Aesir. The best known Vanir—Njörd, Freyr, and probably Freyja—came as hostages to the Aesir. Njörd was the father of the god Freyr and the goddess Freyja.

In his *Germania,* Tacitus described the worship of a goddess, Nerthus, on an island, probably in the Baltic Sea. Whatever symbol represented her was kept hidden in a grove and taken around once a year in a covered chariot. During her pageant, there was rejoicing and peace, and all weapons were laid aside. Afterward, she was bathed in a lake and returned to her grove, but those who participated in her lustration were drowned in the lake as a sacrifice to thank her for her blessings.

Njörd

Nerthus is described as Terra Mater ("Earth Mother"), but her name corresponds to that of the god Njörd (from Germanic *Nerthuz*). Scholars have attempted various explanations of this puzzling change of sex, assuming that the original deity was androgynous or claiming that the loss of feminine nouns of the type *Njörd* represents triggered the reinterpretation of the goddess as a male god. As Njörd is essentially a god of the sea and its riches, it may be preferable to consider Nerthus and Njörd as originally separate gods altogether, whose relationship might be similar to that of Poseidon ("Husband of the Earth-Goddess") and Demeter ("Earth Mother") in Arcadia. Etymologically, the name *Njörd* could then be related to that of the Greek "Old Man of the Sea," Nereus. Before coming to the Aesir, Njörd was supposed to have begotten his two children with his (unnamed) sister. Since such incestuous unions were not allowed among the Aesir, Njörd afterward married Skadi (Skaði), daughter of the giant Thjazi. Evidence from place-names shows that Njörd was worshiped widely in Sweden and Norway, and he was one of the gods whom Icelanders invoked when they swore their most sacred oaths.

Freyr. Much more is told of Freyr, the son of Njörd. His name means "Lord" (compare Old English *Frea*), but Freyr had other names as well; he was called Yngvi or Yngvi-Freyr, and this name suggests that he was the eponymous father of the north Germans whom Tacitus calls Ingvæones (Ingævones). The Old English *Runic Poem* indicates that the god Ing was seen first among the eastern Danes; he departed eastward over a wave and his chariot went after him. It is remarkable how the chariot persists in the cult of the Vanir, Nerthus, Ing, and Freyr. A comparatively late source tells how the idol of Freyr was carried in a chariot to bring fertility to the crops in Sweden. In an early saga of Iceland, where crops were little cultivated, Freyr still appears as the guardian of the sacred wheatfield. Freyr's name often is found as the first element of a place-name, especially in eastern Sweden; the second element often means "wheatfield," or "meadow."

The Eddic poem *Skírnismál* ("The Lay of Skírnir") relates the wooing of Freyr's bride, Gerd (Gerðr), a giant-maiden. This story has often been considered as a fertility myth. Gerdr (from *garðr,* "field") is held fast in the clutches of the frost-giants of winter. Thus, Freyr, as sun-god, would free her. However, this interpretation rests entirely on disputable etymologies. The narrative indicates that Freyr's bride belongs to the otherworld, and her wooing may rather symbolize the affinities of the fertility god with the chthonian powers, dominating the cycle of life and death. Several animals were sacred to Freyr, particularly the horse and, because of his great fertility, the boar.

The centre of Freyr's cult was Uppsala, and he was once said to be king of the Swedes. His reign was one of peace and plenty. While Freyr reigned in Sweden, a certain Frodi ruled the Danes, and the Danes attributed this age of prosperity to him. Frodi (Fróði) was also conveyed ceremoniously in a chariot, and some have seen him as no other than a doublet of Freyr. Freyr was said to be ancestor of the Ynglingar, the Swedish royal family. Such myths are connected with the concept of "divine kingship" in the Germanic world, but earlier views on "sacral royalty" are now being challenged.

Freyja. Freyr's sister, Freyja, shares several features with her brother. She was the goddess of love, wealth, and fertility. She owned precious jewels such as the famous Brísingamen necklace, forged by dwarfs. She is said to be weeping tears of gold for her absent husband, but she is also blamed for being promiscuous. She practiced a disreputable kind of magic, called *seiðr,* which she taught Odin. She was known under various names, some obscure such as Mardöll, and others, such as Sýr ("Sow"), referring to her association with animals. Taking half of those who fall in battle, Freyja had some affinity with the chthonian deities of death.

This relation of fertility goddesses with the otherworld is already illustrated by the Germanic mother goddesses or *matronae,* whose cult was widespread along the lower Rhine in Roman imperial times. They are often represented with chthonian symbols such as the dog, the snake, or baskets of fruit. The same applies to the goddess Nehalennia, worshiped near the mouth of the Scheldt River. Her name may be related to Greek *nekués,* "spirits of the dead."

Guardian spirits. Besides gods and goddesses, medieval writers frequently allude to female guardian spirits called *dísir* and *fylgjur.* The conceptions underlying these two certainly differed originally, although some of the later writers used the words interchangeably.

Dísir and *fylgjur*

Reference is made several times to sacrifice to the *dísir,* held at the beginning of winter. The ritual involved a festive meal and seems to have been a private ceremony, suggesting that the *dísir* belonged to one house, one district, or one family. In an Eddic poem the *dísir* are described as "dead women," and in actuality they may have been dead female ancestors, assuring the prosperity of their descendants.

There is no record of a cult of the *fylgja* (plural *fylgjur*), a word best translated as "fetch," or "wraith." The *fylgja* may take the form of a woman or an animal that is rarely seen except in dreams or at the time of death. It may be the companion of one man or of a family and is transferred at death from father to son.

The elves (*álfar*) also stood in fairly close relationship to men. An Icelandic Christian poet of the 11th century described a sacrifice to the elves early in winter among the pagan Swedes. The elves lived in mounds or rocks. An old saga tells how the blood of a bull was smeared on a mound inhabited by elves.

A good deal is told of land spirits (*landvættir*). According to the pre-Christian law of Iceland, no one must approach the land in a ship bearing a dragonhead, lest he frighten the land spirits. An Icelandic poet, cursing the king and queen of Norway, enjoined the *landvættir* to drive them from the land.

Dwarfs. Dwarfs (*dvergar*) play a part in Norse mythology. They were very wise and expert craftsmen who forged practically all of the treasures of the gods, in particular Thor's hammer. Snorri said that they originated as maggots in the flesh of the slaughtered giant Ymir. Four of them are supporting the sky, made of the skull of this primeval giant. They may have been originally nature spirits or demonic beings, living in mountain caves, but they generally were friendly to man.

BELIEFS, PRACTICES, AND INSTITUTIONS

Worship. Sacrifice often was conducted in the open or in groves and forests. The human sacrifice to the tribal god of the Semnones, described by Tacitus, took place in a sacred grove; other examples of sacred groves include the one in which Nerthus usually resides. Tacitus does,

however, mention temples in Germany, though they were probably few. Old English laws mention fenced places around a stone, tree, or other object of worship. In Scandinavia, men brought sacrifice to groves and waterfalls.

A common word for a holy place in Old English is *hearg* and in Old High German *harug*, occasionally glossed as *lucus* ("grove") or *nemus* ("forest"). The corresponding Old Norse word, *hörgr*, denotes a cairn, a pile of stones used as an altar; the word was also used occasionally for roofed temples. Another term applied to sacred places in Scandinavia was *vé* (compare with *vígja*, "to consecrate"), which appears in many place-names; *e.g.*, Odense (older Óðinsvé).

Temples

Although worship was originally conducted in the open, temples also developed with the art of building. Bede claims that some temples in England were built well enough to be used as churches and mentions a great one that burned.

The word *hof*, commonly applied to temples in the literature of Iceland, seems to belong to the later rather than to the earlier period. A detailed description of a *hof* is given in one of the sagas. The temple consisted of two compartments, perhaps analogous to the chancel and the nave of a church. The images of the gods were kept in the chancel. This does not imply, however, that Icelandic temples of the 10th century were modeled on churches; rather they resembled large Icelandic farmhouses. A building believed to be a temple has been excavated in northern Iceland, and its outline agrees closely with that described in the saga.

Temples on the mainland of Scandinavia were probably built of wood, of which nothing survives, although an influence of pagan temples may be discernible in the so-called stave churches. At the close of the pagan period, the most splendid temple of all was at Uppsala. It was richly described by Adam of Bremen, whose report is based on statements of eyewitnesses, though he may have been influenced by the biblical description of Solomon's temple. Statues of Thor, Wodan, and Fricco (Freyr) stood together within it; the whole building was covered with gold, which could be seen glittering from afar. There were also famous temples in Norway, but no detailed descriptions are given of them.

Sacrifice took different forms. Roman authors repeatedly mention the sacrifice of prisoners of war to the gods of victory. The *thralls* who bathed the numen of Nerthus paid for the revelation of her secret identity with their lives. A detailed description of a sacrificial feast is given in a saga about a king of Norway. All kinds of cattle were slaughtered, and blood was sprinkled inside and out; the meat was consumed and toasts were drunk to Odin, Njörd, and Freyr. The most detailed description of a sacrifice is that given by Adam of Bremen. Every nine years a great festival was held at Uppsala, and sacrifice was conducted in a sacred grove that stood beside the temple. The victims, human and animal, were hung on trees. One of the trees in this grove was holier than all the others and beneath it lay a well into which a living man would be plunged.

There also were sacrifices of a more private kind. A man might sacrifice an ox to a god or smear an elf mound with bull's blood.

Eschatology and death customs. No unified conception of the afterlife is known. Some may have believed that fallen warriors would go to Valhalla to live happily with Odin until the Ragnarök, but it is unlikely that this belief was widespread. Others seemed to believe that there was no afterlife. According to the "Hávamál," any misfortune was better than to be burnt on a funeral pyre, for a corpse was a useless object.

More often people believed that life went on for a time after death but was inseparable from the body. If men had been evil in life, they could persecute the living when dead; they might have to be killed a second time or even a third before they were finished.

The presence of ships or boats in graves, and occasionally of chariots and horses, may suggest that the dead were thought to go on a journey to the otherworld, but this is questionable; such accoutrements more likely reflected a person's earthly occupation. Some records imply that the dead needed company; a wife, mistress, or servant would be placed in the grave with them. The famous Oseberg grave contained the bones of two women, probably a queen and her servant. Some stories suggest the existence of an ancient belief in rebirth, but a medieval writer labels the notion an old wives' tale. On the whole, beliefs in afterlife seem rather gloomy. The dead pass, perhaps by slow stages, to a dark, misty world called Niflheim (Niflheimr).

The end of the world is designated by two terms. The older is Ragnarök, meaning "Fate of the Gods"; the later form, used by Snorri and some others, is Ragnarøkkr, "Twilight of the Gods." Allusions to the impending disaster are made by several skalds of the 10th and 11th centuries, but fuller descriptions are given chiefly in the "Vǫluspá" and the didactic poems of the *Poetic Edda*, which form the basis of Snorri's description in his *Edda*.

Cosmic destruction: Twilight of the Gods

Only a brief summary of this rich subject can be attempted here. Through their own work, and especially because of the strength of Thor, gods have kept the demons of destruction at bay. The savage wolf Fenrir is chained, as is the guileful Loki, but they will break loose. Giants and other monsters will attack the world of gods and humans from various directions. Odin will fight the wolf and lose his life, to be avenged by his son Vidar (Viðarr), who will pierce the beast to the heart. Thor will face the World Serpent, and they will kill each other. The sun will turn black, the stars vanish, and fire will play against the firmament. The earth will sink into the sea but will rise again, purified and renewed. Unsown fields will bear wheat. Balder and his innocent slayer, Höd, will return to inhabit the dwellings of gods. Worthy people will live forever in a shining hall thatched with gold.

Although the cosmic cataclysm portrayed by the poet of the "Vǫluspá" reflects the apocalyptic imagery of the Book of Revelation, it is essentially a symbolic reflection of the waning Germanic world, ineluctably moving to its destruction because of the outrages committed by its divine and human representatives. According to another Eddic poem, the wolf will swallow Odin and, in revenge, his son will tear the jaws of the beast asunder. Several more details are given in other sources, generally cruder than those of the "Vǫluspá."

THE END OF PAGANISM

The Germanic peoples were converted to Christianity in different periods: many of the Goths in the 4th century, the English in the 6th and 7th centuries, the Saxons, under force of Frankish arms, in the late 8th century, and the Danes, under German pressure, in the course of the 10th century. The pagan religion held out longest in the most northerly lands, Iceland, Norway, and Sweden.

The story of the conversion of Iceland is known best because of the wealth of historical documents written in that country during the Middle Ages. Icelanders were, in many ways, the most international of northern Scandinavians. Among those who settled in Iceland in the late 9th century were men and women partly of Norse stock from Christian Ireland. Some of these were Christians; some were mixed in their beliefs, worshiping Christ and Thor at once. There were others who believed in no gods at all. Lack of faith in the heathen gods seems to have grown during the 10th century. Influence of Christian thought on some Icelandic poets is noticeable. Occasional missions to Iceland in the later 10th century are recorded, but little progress was made until Olaf I Tryggvason, king of Norway, sent out the German priest Thangbrand *c.* 997. Thangbrand was a ruthless, brutal man; he was outlawed and returned to Norway *c.* 999. But in the year after Thangbrand left (*c.* 1000), the Icelandic parliament (Althingi) resolved, at the instigation of King Olaf, that all should be baptized, although concessions were made to those who wished to practice heathen rites in private. Many of those who had been hereditary pagan chieftains became leaders of the church and, largely for this reason, tradition survived in Iceland as in no other Scandinavian land.

Conversions to Christianity

The conversion of Norway was far less peaceful. Much is known about it, chiefly from highly colourful Icelandic records. Olaf Tryggvason, who had come to Norway from England *c.* 995, quickly overcame the arch-pagan ruler Haakon Sigurdsson. Paganism was deeply rooted in the

minds of hereditary landowners, as the whole social system was largely founded upon its principles. Using fire and sword rather than persuasion, Olaf converted the whole of Norway in his short reign of five years. When he died in a naval battle, *c.* 1000, many of Olaf's subjects were Christians in name only.

By the time Olaf II Haraldsson (later Saint Olaf) came to the throne about 15 years later, some of the Norwegians had been baptized and some not, and one believed whatever one chose. Olaf II set out to complete the work of his predecessor, resorting to the same methods. He was such a tyrant that his own subjects, Christian though they were, drove him into exile in Russia. When he returned with a motley army, *c.* 1030, he met his death and was soon regarded as a saint. For all his faults, Olaf had established Christianity firmly in Norway.

Very little is known about the conversion of Sweden. It was a slow and complicated process. The people of West Gautland were, apparently, converted earlier than the rest, but public pagan sacrifice persisted in the temple of Uppsala until late in the 11th century. Kings who professed to be Christian were driven out, presumably because of their religious activities. Sweden was hardly a Christian country before *c.* 1100.

The picture that Scandinavian sources provide of Germanic religion is to a large extent lopsided, since many of the documents date to the period when waning paganism was threatened with doom by the growing impact of Christianity. This may account for the pessimistic worldview that pervades some aspects of Eddic poetry, as well as for some rather derogatory descriptions of the behaviour of the gods. The rigorous ethics of early Germanic society, based on trust, loyalty, and courage, and the perhaps somewhat idealized picture of the moral code given by Tacitus, had a divine sanction, but, when Christianity arrived in the north, the message had apparently been dimmed by the gods' disrespect of their most solemn oaths. Paganism no longer had the stamina and inner drive to resist the pressure of Christianity, with its strong, well-organized church and its positive monotheistic creed, encompassing faith and ethics. (E.O.G.T.-P./E.C.Po.)

Finno-Ugric religion

The religion of the Finno-Ugric peoples, who inhabit regions of northern Scandinavia, Siberia, the Baltic area, and central Europe, is an admixture of agrarian and nomadic primitive religion and of Christianity and Islām. This treatment is concerned primarily with the pre-Christian and pre-Islāmic elements of Finno-Ugric religion.

GEOGRAPHIC AND CULTURAL BACKGROUND

The Finno-Ugric peoples. The area inhabited by the Finno-Ugric peoples is extensive: from Norway to the region of the Ob River in Siberia and southward into the Carpathian Basin in central Europe and Ukraine. The history of their geographic dispersion is based almost entirely on linguistic criteria, since historical knowledge is nearly and archaeological finds are scanty and interpreted variously.

Geographic distribution

The Finno-Ugric languages and the Samoyed languages together form the Uralic family of languages, which began to split up about 5000–4000 BC. The original Uralic people are thought to have lived in the region between the Ural Mountains and the middle reaches of the Volga River. Their descendants in the north are the Nenets, who live on the shores of the Arctic Ocean between the Taymyr and the Kanin peninsulas. In the south the original speakers of the parent Finno-Ugric language probably began to disperse by 3000 BC, when the Ugrians formed their own group. One branch moved northeast, behind the Ural Mountains: the Ostyak (who in their own language call themselves Khanty), living east of the Ob River, and the Vogul (who call themselves Mansi), living west of the Ob River. The other branch spread southward and made contact with the Bulgar Turks and the Khazars; in 895 this branch (the Magyars [Hungarians]), together with certain Turkish tribes, conquered what is now Hungary. In this way, the largest, but at the same time linguistically the most isolated, Finno-Ugric nation came into existence. Other Magyars live in the countries of Romania and Slovakia.

The Permian branch of the Finno-Ugric populations living in central Russia split from the other groups between 2500 and 2000 BC; the linguistic differentiation is not very great between the present-day Permians, who are divided into Votyaks (called Udmurts, living between the Kama and Vyatka rivers) and Zyryan (called Komi, living in the region between the upper reaches of the Western Dvina River, Kama, and Pechora)—the differentiation only occurred a little over 1,000 years ago. An intermediary group between the two branches are the Permyaks, whose language is sometimes considered a dialect of Zyryan.

Farther to the south, the differentiation of the Volga Finns into separate groups probably began about 1200 BC. The Volga Finns consist today of the Mordvins (including the Moksha in the southeast and the Erzya in the northwest), living in a rather large region near the middle reaches of the Volga River, and the Cheremis (the Mari), living in the vicinity of the confluence of the Volga and the Kama.

When the Baltic Finns came to the regions bordering the Baltic Sea is not certain. The latest possible date would be *c.* 1500 BC (the evidence being the Baltic loan words in proto-Finnic), when the "proto-Finns" still maintained contact with the Mordvins and the Lapps. A much earlier date is possible, however, as there must have been many and repeated migrations by the Finno-Ugric populations westward from the Ural Mountains toward the Baltic regions. Initially, settlement was sparse, as is always the case with hunting cultures, but language differentiation sped up with the change to sedentary agriculture. The Lapps (called the Saami or Sami) have been the slowest of the Finno-Ugric peoples to relinquish the hunting and nomadic culture—which has withdrawn slowly toward the north—and they themselves have moved from the direction of Lakes Ladoga and Onega (northeast of St. Petersburg) to the northern parts of Fennoscandia and the Kola Peninsula (far northern Russia).

After separating from early proto-Finnic about 3,000 years ago, the Lapp language became divided into a number of very different dialects. The oldest population settlements of the Baltic Finns were to the south of the Gulf of Finland and to the south of Lake Ladoga. The most westerly group, the Livonians (in the north of Courland, now part of Latvia), is disappearing. The Estonians are one of the three most advanced of the Finno-Ugric peoples, the others being the Finns and the Hungarians. Small but interesting cultures are represented by the Greek Orthodox Votes and Izhora Ingrians, both nearly extinct groups living near the head of the Gulf of Finland in an area once called Ingria, the Veps (living near Lake Onega), and the Karelians (living in central Russia, Karelia, and Finland), as well as the Ludes in Olonets, who speak a transition dialect. The population moved into Finland from the south and southeast.

Influences on Finno-Ugric religion

Ecological and intercultural factors. To attain a proper understanding of the history and phenomenology of the religion of the Finno-Ugric peoples, two basic influences must be borne in mind: the ecological factors and the pressure of alien cultures on the original religious tradition. The result of both factors has been a great variation in the religious atmosphere in different places.

The Lapps, Nenets, Vogul, and Ostyak—who all have been associated with a nomadic and hunting culture in Arctic regions—retain a religious life that has many ancient elements. The Finns, Karelians, and Zyryans have practiced hunting up to the present, but they have been familiar with agriculture for thousands of years. The peoples on the south side of the Gulf of Finland, such as the Estonians, have long practiced agriculture and cattle breeding as well as fishing, but hunting has not been as important to them. The Finno-Ugric peoples of the southeast, like the Votyaks and the Cheremis, have practiced agriculture and cattle breeding only. The agrarian economy of the Hungarians, with its seminomadic features, is the outcome of a complicated history.

Habitat, climate, and other ecological factors have had

an important influence on economy and social organization and on traditional religion. Some of the differences between the various Finno-Ugric peoples, however, can be traced to outside cultural influences. The southeastern Finno-Ugric peoples have been marked by Turko-Tatar influence. In the 8th century the Votyaks and the Cheremis came under Bulgar domination; the conversion of the Bulgars to Islām in 922 and the subsequent Tatar domination in eastern Russia (1236–1552) gave added significance to the Arab–Islāmic tradition. In the 16th and 17th centuries, the Volga Finns, the Permians, the Ob Ugrians, and the Nenets finally came under the domination of Moscow; before this, Orthodox missionaries had worked, for example, among the Zyryans (St. Stephen, 14th century) and the Baltic Finns.

The influence of Slavic tradition on the Finno-Ugric peoples has been considerable—from the point of view of both folk religion and the more institutionalized Orthodox faith, though some of this influence in many places is late and superficial. There are also Finno-Ugric substrates in the Russian tradition in the north and northwest of Russia. Pre-Christian practices were still alive in the early 20th century, and among the Votyaks, the Ob Ugrians, and the Nenets there were still people who were unbaptized. Roman (Catholic) and Byzantine (Orthodox) traditions met one another in Finland and Estonia, but the Orthodox groups remain established only in the eastern regions. Most of Finland was converted to Christianity by way of Sweden, beginning in the 12th century, and the country remained Roman Catholic until Lutheranism was established in the 16th century. The position of the Hungarians, who formed a pocket surrounded by alien cultures, resulted in an extremely mixed array of contacts at different levels.

Thus, each of the Finno-Ugric peoples has its own cultural history, habitat, and level of civilization. In considering their religion, all this must be borne in mind. The Hungarians, Finns, and Estonians have the longest literary traditions, while a number of the other peoples are only now developing written literature in their own language. Ancient popular belief, preserved in oral tradition, has for the most part developed more persistently on the periphery, but near centres of culture it has become a minor growth alongside institutional religions.

Difficulties involved in the study of Finno-Ugric religion

The problem of the concept of a Finno-Ugric religion. Since it is not possible to find a single formula to cover Finno-Ugric cultures and religions and since the relationship between the peoples is often distant both geographically and historically, it may well be asked whether there is any utility in attempting, by means of comparative methods, to discover some common or basic substratum in Finno-Ugric religion. Many earlier scholars attempted this enthusiastically, but today there is general agreement that a hypothetical reconstruction representing the "original religion" of a single language family is virtually impossible. That ancient tradition may have been preserved in different regions, although fragmented and adapted to new conditions, is, of course, possible, and indeed seemingly trustworthy discoveries have been made that substantiate this view. One must, however, be extremely circumspect in projecting hypotheses applying to the entire linguistic group. Genetic-historical considerations are of great importance when dealing with those areas of the language family where a cultural connection has subsisted long and late.

The search for a common historical tradition is not, however, the most rewarding aspect of the study of Finno-Ugric religions. The religio-phenomenological approach is equally interesting and significant. In the course of conducting nonhistorical studies of similarities and differences in Finno-Ugric religious material, scholars have uncovered a spectrum of basic religious forms running from Arctic hunting and fishing cultures to southern cattle breeding and agriculture.

MYTHOLOGY

Creation, cosmography, and cosmology. The most widespread account of the creation among the Finno-Ugric peoples is the earth-diver myth. In the north it is known in an area extending from eastern Finland to the Ob River, and in the south it is found, for example, among the Mordvins. This myth, which is well known in North America and Siberia, is fairly constant in form among the Finno-Ugric peoples. In the Mordvin variant, God sits on a rock in the middle of the primeval sea and spits into the water; the saliva begins to grow and God strikes it with a staff, whereupon the Devil comes out of it (sometimes in the form of a goose). God orders the Devil to dive into the sea for earth from the bottom; at the third attempt, he succeeds but tries to hide some of the earth in his mouth. While God scatters sand, the earth begins to grow and the Devil's deceit is unmasked, and the earth found in his cheek becomes mountains and hills. The eastern Finnish myth contains an interesting detail; God stands on the top of a golden statue and orders his reflection on the water to rise, and this becomes the Devil.

Etiological (explanatory and expanding) continuations of the basic myth are common; the Devil demands for himself a piece of earth the size of the end of a stick, and from the hole that results vermin emerge—mice, fleas, mosquitoes, flies, and other such living things. Indo-Iranian influence has been seen in the dualism of the myth—setting God against the Devil—since religious dualism is most significant in Indo-Iranian religion. A water bird may be older than the Devil; it also occurs, however, without the dualistic emphasis. Thus, in an account by the Yenisey Ostyak, the great shaman (a medicine man with psychic abilities) Doh glides above the primeval sea among the water birds, asks the red-throated loon to dive for earth from the bottom of the sea, and with the earth makes an island. A rarer, but apparently ancient, myth is found among the Vogul: the god of the skies lets earth come down from heaven and places it on the surface of the great primeval sea.

Cosmic egg myth

The world made from an egg is a myth best known in equatorial regions, though the most northerly points of its distribution are in Finland and Estonia. A water bird or an eagle makes its nest on the knee of the creator (Väinämöinen), who is floating in the water; it lays an egg, which rolls into the water, and pieces of it become the earth, the sky, the moon, and the stars. Myths concerning the creation of man are found in the north among the Vogul and in the south among the Volga Finns. The common element among all such myths is that man, on the brink of achieving perfection, had his hairy covering transferred to the dog by the Devil, whose spit blighted man and made him subject to disease and death. In Finland the variant of yet another anthropogonic (origin of man) myth has been found: a hummock rises from the sea, a tree stump thereon splits open, and the first human couple steps forth.

Finno-Ugric cosmographic (world-describing) concepts include the following well-known mythological themes: a stream or sea encircling the round world; a canopy of the heavens, the central point of which is the North Star (a kind of nail on which the sky rotates); a world pole supporting the sky; a world mountain and a world tree rising in the middle of the earth; animals carrying the earth; and the nub of the earth and the nub of the sea (an abyss that swallows ships). From these and from other materials more or less coherent cosmographies have been formed in different places; the central components are the sky, the earth, and the underworld. Among the Ob Ugrians and the Nenets is found a myth of the seven- or nine-storied heaven.

The cosmogonic (concerning the origin of the world) and cosmographic myths have had important ritual functions and have provided the basis for cosmology (the ordering of the world). When, in incantations and prayers, numerous natural, cultural, and social phenomena derive from these basic myths, it is not a matter of giving an explanation but of finding the connection with the decisive primeval events that gave the world its lasting order. A pillar representing the world pole has been worshiped by the Lapps and the Ob Ugrians, especially as a symbol of the world order.

High gods. The semantic elements "sky" and "god of the sky" are found to be so close in the terminology of certain of the Finno-Ugric peoples (for example,

Cheremis Jumo, Finnish Jumala, Votyak Inmar, Zyryan Jen, Nenets Num) that the association cannot be a recent phenomenon. The tradition of the god of the sky is many-layered, and the influence of monotheism, especially of Christianity and Islām, is widely exhibited. This influence was evidently preceded by that of ancient southern high cultures. Thus the Cheremis Jumo has a real court with servants in his heaven, and these servants act as intermediaries between humans and the god of the sky. This indicates a Turko-Tatar influence, which can also be seen in the Votyak Inmar; Christian elements, however, are also found (Inmar's mother is related to the Virgin Mary). "Great," the most common epithet for Inmar and Jumo, reminds one of Allāh. The Mordvin god of the sky (Škaj, "creator" or "birth giver," among the Moksha people, and also Niškē-pas, "the great inseminating god") is the chief of the gods, all-knowing and all-seeing, who is not approached for trivial things. He appears, however, very concretely in a festival connected with the beginning of the spring plowing. In this festival an old man represents the god of the sky and from an attic or a tree answers questions put to him by people who pray about health, the grain harvest, the weather, and other matters. The gods of the sky of the Arctic Finno-Ugric peoples (Nenets Num; Ostyak Num-Turom and Sängke; Vogul Num-Tarom; Lappish Tiermes, Horagalles, and Radien) are the high gods of hunting and nomadic cultures, who sometimes appear in myths as creator gods and culture heroes (often as *dei otiosi,* or "inactive gods," without a cult) and sometimes as venerated gods of the economy (as the promoters of fishing, hunting, and reindeer herding), especially as weather gods. Originally the Finno-Ugric peoples probably had no concept of a hierarchic family of gods with a supreme god at its head; the attribute found in many places, "lofty" or "high," merely means "being above"—that is to say, a god appearing in the sky.

The concept of a begetting sky is stressed in southern agricultural cultures, in which an increasing importance of the Earth Mother may be observed; it is no longer a mere local field spirit but rather has the role of a great birth giver. "The god of the sky is our father, and the Earth Mother is our mother," say the Mordvins. The Earth Mother's function is not limited to field sacrifices, but also includes child giving; she is the begetter par excellence.

System of spirits. The high gods are usually encountered in connection with a rite; they are distant, invisible, and do not make surprise visits. With the guardian spirits, however, matters are different. They are first and foremost supranormal beings that appear in definite visions, auditory experiences, and other such occurrences. They appear especially when a social norm involving a guardian-spirit sanction is broken. The guardian spirits—along with the spirits of the dead—are significant as regulating factors in daily behaviour and normally are solitary local spirits, believed to "govern" and "own" a particular area: a cultural locality (*e.g.,* household spirits), a natural region (*e.g.,* guardian spirits of forest or water), or a natural element or phenomenon (*e.g.,* fire spirits or wind spirits). There are also special guardians (of man or of treasure) and various demonic beings that—though similar to the guardian spirits—are not worshiped.

The names of guardian spirits are normally compounds of words, the first element of which indicates the sphere of action and the second being a name such as "man" or "master," as in Votyak Korka-murt ("House-man") or Vu-murt ("Water-man"); "old man" or "old woman," as in Cheremis Pört-kuguza ("the Old Man of the House") or Pört-kuwa ("the Old Woman of the House"); or "father" or "mother" as in Mordvin Jurt-at'a or Jurt-ava. The system of social values is revealed by the system of guardian spirits: The house spirit protects the luck of the home; the cattle spirit watches over the cattle during the winter (in the summer the cattle come under the forest spirit); and the barn spirit looks after threshing luck. In representing these values the spirit may appear in a number of roles. Thus, the Ingrian house spirit appears as "owner," the original owner of the plot on which a house is built; "moralist," punisher of crimes against norms that may endanger the luck of the house; and "sympathizer,"



Wooden images of Ostyak house spirits.
From K.F. Karjalainen, *Die Religion der Jugra-Völker;* reproduced with permission from the Finnish Academy of Science and Letters

one who warns in advance of catastrophes threatening house or family. With some peoples—the Mordvins, for example—the guardian-spirit system is very specific and there are a very large number of spirits; with others, such as the Lapps, the Nenets, and the Ob Ugrians, there are fewer of them, and Herr der Tiere ("Master of Animals") game spirits predominate.

Sacred ancestors. The oldest form of Finno-Ugric religion is thought to be ancestor worship. Some of the main terms (*e.g.,* "grave," "hades," and "soul") go back several millennia. The cult concerned only dead members of the family; other dead beings were experienced as restless haunters, and aggressive expelling rites were used to dispel them. The worship of ancestors must be understood as a family institution in which intercourse between the living and the dead is the internal activity of a social primary group. The dead belong to the family, and they have both rights and duties; they protect the happiness of the family, assist it in its means of livelihood, and receive their share of the produce; they are also considered to be counselors, moralists, and judges. The cult of the dead can be divided in the following manner: (1) rites at the moment of death; (2) funeral preparations (washing the corpse, attiring it, and watching by it; making the coffin); (3) the committal; (4) celebrations in memory of a single dead person; (5) annual memorial ceremonies for the dead; (6) offerings and prayers to the dead in connection with earning the means of subsistence; and (7) occasional rites (*e.g.,* when moving to a new place or during illness).

The most important of the ritual ceremonies for a dead person are those that take place during the transition period, which may last for six weeks and may include addressing the departed euphemistically and in dirges. The departed person remains in the dwelling place, separated from his body; agreements are made with him about the distribution of property; he is given advice about how to live on the other side; he is invited to return for the celebration of his anniversary; and so on. The most important matter is the ensurance of harmony between the newly departed and his relations in the graveyard. Of central importance in the collective worship of the dead is the visit of the departed members to their old home; among the Eastern Finno-Ugric peoples this approximates with the Chris-

tian feast of Easter, and among the Western it is in late autumn (*e.g.*, the Finnish Kekri, November 1, an ancient festival to celebrate the seasonal change). Living members of the family also visit the graves on the anniversary days of the departed. Customs among the Lapps, the Nenets, and the northern Ostyak differ somewhat from the above; among the Lapps, the departed person is represented by a clothed log and among the Ostyak and the Nenets by a doll-effigy that is kept for as long as three years.

The otherworld is viewed as two-storied and consists of first, a graveyard hades, or underground village of the dead in a holy forest near the village; and second, a distant hades, far in the north behind the burning stream (with an admixture of paradise concepts). Name-giving rites suggest continuity and reincarnation; a child is given the name of a dead relative, and the child thereby is believed to receive the personality of the deceased relation. If the result is unsuccessful, a name-changing rite can be performed.

Divine heroes. Hero worship in Finno-Ugric religion does not point to culture heroes who are described in myth and whose actions are located in cosmogonic contexts. In general, culture heroes are not worshiped. The matter is otherwise when dealing with divinized historical figures, the cults of which are found among several of the Finno-Ugric peoples. Mardan of the Yelabuga Votyak is viewed as the progenitor of 11 villages and the one who led the dwellers therein from the north to their present habitations. There is a sacrificial ceremony in his honour every year. Also, there are signs of the worship of tribal chiefs, for example, in the forest sanctuary worship of the Votyak (*lud*) and the Volga Finns (*keremet*). The best-known of the Cheremis princes, called "the old man of the Nemda Mountain," is a great ancient warrior under whose rule the people were strong and united. According to this myth, he promised to return when war threatened; once he was called for unnecessarily and, after discovering the betrayal, he ordered the annual propitiation sacrifice of a foal. The Ob Ugrians have a large number of "local gods" of whom pictures have been made and who are sometimes associated with ancient mighty men or Christian heroes and saints. A death doll made by a shaman may also have been the origin of a hero cult; the Nenets have been known to cherish and feed such a doll for as long as 50 years.

Sacred animals. In the "hunters' religion" preserved among the northern Finno-Ugric peoples, bear ceremonies are central. The Ostyak, Vogul, Nenets, Lapps, Finns, and Karelians have all been acquainted with myths and rites connected with the bear. The myths recount that the bear is of heavenly origin and is the son of the god of the sky; it descends from heaven and, when it dies, returns there. There is also a story about a marriage between a bear and a woman from which a tribe of the Skolt Lapps (in Finland) is said to be descended. The bear-killing ceremony is divided into two acts—the killing itself and the feast afterward. Killing a bear that was protected by a forest guardian spirit involved a complicated ritual, which ended with bringing the bear home. Women believed that they had to keep at a distance so that the bear would not make them pregnant. The feast to celebrate the killing of the bear lasted two days and was full of marriage symbolism. The bear was addressed euphemistically, and a young man or woman was chosen to be its mate. A large meal made of the meat of the bear was consumed. Finally, the skull of the bear was carried in procession to the branch of a pine tree on the top of a mountain. This was the custom in Karelia. A number of miniature dramas were connected with Ob Ugrian bear rites. Masked participants tell the bear that members of a strange tribe have killed it. There seems to be a historical connection among the bear ceremonies of Ob Ugrians, Karelians, Finns, and Lapps. Nowhere else in the wide Arctic sphere have the bear songs and dramas taken such a prominent place as in this hunting ritual.

Bear ceremonies

The exogamic patrilineal clans (involving marriage outside a particular group) of the Ob Ugrians are often known by animal names—"bear," "falcon," "frog," or "dog." The animal is regarded as the manifestation of the family guardian spirit and is not allowed to be killed or eaten. Evidence of totemistic systems, in which animals are associated with blood-related groups, has been found among the Lapps and the Nenets. Some scholars consider the names of relations (animal names) found among other Finno-Ugric peoples, such as the Hungarians and Karelians, as evidence of a lost totemism.

INSTITUTIONS AND PRACTICES

Cult authorities. The male head of the family has long had a central role in leading different home and family cults. In the *lud* sanctuaries of the Votyak, for example, worship was performed by members of the family; the head of the family had the responsibility of organizing the cult and the task was hereditary. Women also were able to supervise certain minor home rituals—such as those performed in connection with cattle breeding (offerings to the guardian spirit of the cattle shed and the forest). In hunting and nomadic cultures, the head man (*e.g.*, the oldest of the hunting party or the reindeer chief) supervised the rites. The official authorities of the rites (*i.e.*, the religious specialists) among the Finno-Ugric peoples were of the following types: shamans (among the Nenets and the Lapps); seers (the counterparts of the shaman among southern peoples); sacrificing priests (the leaders of the annual rites, especially in cattle-breeding cultures and agricultural communities); guardians of the sanctuary (the protectors of holy groves, buildings, and other places and the controller of the rites); professional weeping women (the "vocalists," especially of the cult of the dead but also of weddings, who were the verbal expressers of the content of the ritual); and the masters of ceremonies at weddings. The shaman had many and various tasks in Arctic regions, but further south particular tasks were undertaken by various cult authorities: the seer (healing and counseling) and the weeping woman, or psychopomp (*i.e.*, "conductor of souls"), guiding the soul to the other world. The two last-mentioned are verbal ecstatics; the task of the seer, especially in solving critical problems, was of the utmost importance. The task of the sacrificing priest was more of a routine affair, but among the Volga Finns and the Permians for example, the long and skillful prayers as well as the complex ceremonies performed by the priests required great professional competence.

Cult centres. The home sanctuary of the Votyak is *kuala*, a primitive log cabin near the dwelling house. In a corner at one end of the *kuala* is a shelf, at the height of a man, on which there are branches of deciduous trees and conifers, and on top of them a *voršud* (a box with a lid). A weekly offering is made here. Another Votyak sanctuary is the *lud*—a fenced-off area in an isolated place in the forest. In the middle is a primitive table for sacrificial gifts. In the *lud* regular animal sacrifices are offered and occasional crisis rites performed (sacrifices to dispel accidents or disease). The cult group in both *kuala* and *lud* is the family; the office of the sacrificing priest of the *lud* is hereditary, and in the principal house of the family there is a great *kuala*, which is visited three times a year in addition to the offerings made in the small *kuala* at home. The small *kuala* is built on a foundation of earth and ashes brought from the big *kuala*. The system is exogamous—the woman visiting the *kuala* of her own father and not that of her husband's father. The Votyak also have large groves near a spring or a brook in the vicinity of a village, where common sacrifices for the whole village are made. There are, in addition, larger sacrificing groups, which may include dozens of villages and which meet every third year for a festival lasting many weeks. The Volga Finns also have fenced-in *keremet* groves for the family cult and places of worship common to the whole village. Evidence also exists concerning sacrificial groves among the Baltic Finns and from group villages in Karelia and Ingria. In the thinly populated parts of Finland, the family cult took place either at cup stones (sacrifice stones with shallow cuplike depressions) or at holy trees. Among the nomadic Lapps (those involved in reindeer herding and fishing) *seita* ("sacrificial stone") places for worship arose near a reindeer migration route or a good fishing place, and for such a place an outstanding stone generally was chosen. The Ob Ugrians had a kind of "mobile temple"

Home and forest sanctuaries

for the wooden idols (normally kept in the corner of the house) that were placed on special sledges.

Cult practices. All the main categories of rites are found among the Finno-Ugric peoples: cyclic or calendric rites (concerning the means of livelihood), rites of passage (the transition of the individual from one status to another), and crisis rites (concerning threats of disaster). The character of these rites varies considerably, depending on ecological factors and cultural contacts. Generally, an agrarian culture produces a cult system that is more stable and formal than that produced by a mobile hunting culture or a nomadic way of life. In the latter, sacrifice rites tend to be more improvised and the cult group smaller. An example of a formal system is the distinction "upward" and "downward" in worship found among the Votyaks and the Cheremis; sacrifices of white animals are made in deciduous groves to the god of the sky and to certain nature gods, the direction of prayer being to the south; sacrifices of black animals are made to the departed and to the guardian spirits of the earth near conifers, the direction of prayer being to the north.

CONCLUSION

Two phenomena may be consistently observed with regard to the religious customs of the Finno-Ugric peoples. These are the ecological adaptation of religion and the stratification of tradition in connection with acculturation. A number of examples of the former have already been given. As far as acculturation is concerned, it may be said that the "syncretism" it produces does not result in any conflict in the religious field, except perhaps for short periods of adjustment. Old and new elements of different origins are molded into an active system, and choice and adaptation take place according to practical religious need. Christianity and Islām have in many places provided a religious superstructure, but they have not been accepted as such; certain elements from them have been adapted to the depth structure of a primitive religion. The best example of this is the preservation of folk religion in Hungary, Finland, and Estonia, where Christianity, supported by a literate culture, is ancient. Popular belief has become intertwined with the religious tradition because it has always had a function that no Christian practice has replaced. Only mass media and urbanization have jeopardized the ancient belief tradition. (L.O.H.)

Baltic religion

The term Baltic religion covers the religious beliefs and practices of the Balts, ancient inhabitants of the Baltic region of eastern Europe, who spoke languages belonging to the Baltic family of languages.

THE STUDY OF BALTIC RELIGION

Problems. The study of Baltic religion has developed as an offshoot of the study of Baltic languages—Old Prussian, Latvian, and Lithuanian (see LANGUAGES OF THE WORLD: *Indo-European languages: Baltic languages*). These form a separate group—the oldest one—of the Indo-European languages, which are closely related to the ancient Indian language Sanskrit.

Although the study of Baltic languages is important in the study of Indo-European linguistics, the study of Baltic religion has not assumed a similar level of importance in the study of comparative religion. In 1875 it was shown that the religious concepts of the Balts, when compared with those of other European peoples, are found to be marked by many older features that agree with Vedic (ancient Indian) and Iranian ideas. At least one scholarly reconstruction of ancient Indo-European religion depended mainly on Baltic religious traditions. International research in Baltic religion has, however, been greatly hindered by the fact that the languages of these small Baltic countries (Latvia and Lithuania) are but little known and because Baltic scholars have been able to work in this field only relatively recently. Thus, a comprehensive review of Baltic religion is possible only on the express understanding that many findings are only hypothetical and require further research. But, as will be seen below, even under these circumstances Baltic religious concepts help greatly in understanding the formation and structure of the oldest phases of Indo-European religion.

Age of religious concepts

Sources of data. There are four main sources of data, each with its own relevance and each requiring its own specific methodology: archaeological material, historical documents, linguistics, including toponymy (the study of the place-names of a region or language), and folklore. Since the last half of the 19th century, archaeological material has furnished much information about burial and sacrificial rites. The remains of sacred buildings have also been found. This material is of special interest in that it corroborates old religious traditions preserved by folklore, which gives added reliability to both of these sources. But archaeological material can at best furnish only a partial and incomplete picture, even though it is meaningful in some respects. Historical documents, already partially compiled and published, could be expected to yield much more information. Their value, however, is made problematic by the fact that all such documents were written by foreigners, mainly Germans who, in the course of their centuries-long eastward expansion, subjugated the Baltic peoples and exterminated some of them. Since the conquerors did not understand the Baltic languages, many documents contain the names of gods and other divinities that are without basis in fact. Baltic religion was viewed dogmatically and negatively in the light of Christian interpretations. Linguistic source material, also compiled by foreigners, shows fewer signs of interpretation, especially in regard to toponymy. Baltic folklore—one of the most extensive folklores of all European peoples—contains the greatest amount of material, especially in the form of *dainas* (short folk songs of four lines each) and folktales. Folklore is especially valuable because it contains many concepts that elsewhere have been lost under the influence of Christianity. Old religious beliefs have persisted because the Germans, after conquering the Baltic lands in the 13th and 14th centuries, made practically no attempt at Christianization and contented themselves with only economic gains. The positive result of this policy is the preservation of old traditions and religious beliefs; some researchers have also noted the similarity between the metrical structure of the *dainas* and that of the Old Indian short verses in the Rigveda (a Hindu sacred scripture).

The student of Baltic religion still encounters two difficulties. First, as has been noted, since written documents were established in Christian times, Christian influences in them are inescapable. Such influences cause difficulties and make a critical approach mandatory. Second, after the establishment of political independence of the Baltic countries following World War I, there arose a certain national romanticism that has attempted to identify Baltic culture with that of the ancient Indo-Europeans. Thus, an uncritical approach has led even to the introduction of "gods" that are actually only etymological derivations from the names of Christian saints. On the other hand, those western European scholars who are unfamiliar with the special historical and social circumstances of the Balts have assumed Baltic folklore to be on a level with the thoroughly Christianized western European folklore and thus have underestimated its importance.

MYTHOLOGY

Cosmology. In the traditions of the Baltic peoples, there are no epic myths about the creation of the world and its structure. This fact is explained by the historical and social circumstances mentioned above, which either have hindered the formation of these types of myths or, more likely, have simply made their preservation impossible. Furthermore, there has been no significant research concerning Baltic myths and their interrelationships. Fragmentary evidence found exclusively in folklore indicates only two complexes of ideas with any certainty: the first concerns the structure of the world, the second the enmity between Saule ("Sun") and Mēness (Latvian; Lithuanian Mėnulis; "Moon").

The two-region hypothesis

There is disagreement as to whether the Balts pictured the world as consisting of two regions or of three. The two-region hypothesis seems to be more plausible and is

supported by a dualism found frequently in the *dainas*: *šī saule* (literally "this sun") and *viņa saule* (literally "the other sun"). The metaphor *šī saule* symbolizes ordinary everyday human life, while *viņa saule* indicates the invisible world where the sun goes at night, which is also the abode of the dead.

The evidence does not show conclusively whether this world is located in the direction of the setting sun or under the earth, beneath which the sun travels back to the east. The sky is considered to be a mountain, sometimes of stone, and is the residence of the sky gods. Saule rides over the sky in a chariot drawn by a varying number of horses, Mēness rides to be married, and Pērkons (Latvian; Lithuanian Perkūnas; "Thunderer") makes weapons and jewelry in the sky.

The concept that Saule, unseen during the night, makes her way from west to east under the earth so that she can start her course anew over the sky mountain is also familiar. It is also possible to see here the ancient idea of a world ocean on which the earth, as a round plate, swims, an idea that has disappeared under the influence of Christianity.

The notion of a sun tree, or world tree, is one of the most important concepts regarding the cosmos. This tree grows at the edge of the path of Saule, and the setting sun (Saule) hangs her belt on the tree in preparation for rest. It is usually considered to be an oak but is also described as a linden or some other kind of tree. The tree is said to be located in the middle of the world ocean or generally to the west.

The gods. *Dievs.* The Baltic words Latvian *dievs,* Lithuanian *dievas,* and Old Prussian *deivas* are etymologically related to the Indo-European *deiuos;* among others, the Greek Zeus is derived from the same root. It originally meant the physical sky, but already in Old Indian and other religions the sky became personified as an anthropomorphic deity. Dievs, the pre-Christian Baltic name for God, was used by Christian missionaries (and still is) to denote the Christian God. The etymology of the word indicates that the Balts preserved its oldest forms, which is also true of the functions and attributes of the personified Baltic sky god Dievs, who lives on his farmstead on the sky mountain but does not participate in the work of the farm. Importantly, Dievs is a bridegroom who rides together with the other gods to a sky wedding in which his bride is Saule. Dievs' family is a later development; in the family, Dieva dēli ("God's Sons") play the primary role. Thus Dievs is pictured as the father of a family of sky gods. Besides such anthropomorphic characteristics, another characteristic that gives Dievs a universal significance may be observed: he appears as the creator of order in the world on the one hand, and as the judge and guardian of moral law on the other. From time to time he leaves the sky mountain and actively takes part in the everyday life of the farmers below. His participation in various yearly festivals is vividly described. In spite of this, the Baltic Dievs is similar to the Old Indian Dyaus, the Greek Zeus, and other personifications of the sky. Such divinities have a tendency, in comparison with other gods of their religions, to recede into a secondary role.

The sky god

Pērkons. In Baltic, as in other Indo-European religions, there is, in addition to Dievs, the Thunderer (Latvian Pērkons, Lithuanian Perkūnas) with quite specific functions. Pērkons is described in the oldest chronicles and in poetic and epic folklore, but, though he is a primary divinity, there is no reason to believe that he is the main god. His abode is in the sky, and, like Dievs, he sometimes descends from the sky mountain. He has two main characteristics. First, he is a mighty warrior, metaphorically described as the sky smith, and the scourge of evil. His role as adversary of the Devil and other evil spirits is of secondary importance and has been formed to a great extent under the influence of Christian syncretism. Second, he is a fertility god, and he controls the rain, an important event in the life of farmers. Various sacrifices were made to him in periods of drought as well as in times of sickness and plague. No other god occupied a place of such importance at the farmer's table during festivals, especially in the fall at harvest time. Like the other sky gods, he also has a family. Even though his daughters are mentioned occasionally, originally he had only sons, and myths depicting sky weddings portray his role vividly, as a bridegroom and as the father in his sons' weddings.

Saule. The Sun, Saule, occupies the central place in the pantheon of Baltic gods. The divinity of the sun has been recognized throughout the world, and the Balts were no exception. The Baltic description of Saule is so complete and specific that it was one of the first to be studied by scholars. Of greatest importance is the similarity in both functions and attributes of Saule and the ancient Indian god Sūrya. Similarities between the two deities are so great that, were not the two peoples separated by several thousand miles and several millennia, direct contact between them would be indicated instead of only a common origin.

The sun goddess

The representation of Saule is dualistic in that she is depicted as a mother on one hand, and a daughter on the other. Her attributes are described according to the role she plays. As a daughter she is mentioned only when she is a bride to the other sky gods. But as her daughters frequently are in the same role, it is difficult to differentiate between them. As a mother, however, she is depicted much more extensively and completely. Her farmstead on the sky mountain borders that of Dievs, and both Dieva dēli and Saules meitas ("Daughters of the Sun") play and work together. Sometimes Dievs and Saule become enraged at each other because of their respective children, as, for example, when Dieva dēli break the rings of Saules meitas or when Saules meitas shatter the swords of Dieva dēli. Their enmity lasts three days, which some scholars explain through natural phenomena; *i.e.,* the three days before the new moon when Dievs, a substitute for the moon, is not visible.

That Saule, richly described in mythology, also had a cult devoted to her is suggested by the many hymns in her honour. They contain either expressions of thanks for her bounty or prayers seeking her aid, not only in relation to agriculture but to life in general. In agriculture Saule is a sanctifier of the fertility of the fields; in the life of the individual she is a typical sky goddess, interfering in her omniscience. She has human moral characteristics and punishes the immoral and aids the suffering. Though the question of where Saule's places of worship were located is not solved, the occasions for rituals pertaining to Saule have been definitely established, the most important of which was the summer solstice. Besides song, recitative, and dance, a central place in the ceremonies was occupied by a ritual meal, at which cheese and a drink brewed with honey (later beer) were consumed.

Mēness. The Moon, Mēness, also belongs to the sky pantheon. Detailed analysis only recently has shown that he has a role as a war god in Baltic religion. Such a role is indicated not only by his dress and accoutrements but especially by his weapons and expressions used in times of war. The influence of syncretism, however, has erased the outlines of his characteristics so far as to make a description of his role and any cult he may have had very difficult. The sky wedding myths furnish a somewhat more complete picture in which he is represented as a conflict-creating rival suitor of Auseklis ("Morning Star").

The moon god

Auseklis, his sons, Dieva dēli, and Saules meitas form a separate group of divinities. Although they are mentioned in the sky myths, they have remained only as personifications of natural phenomena, characterized by the most beautiful metaphors. It is notable that a common characteristic of the sky gods, and, in fact, of all Baltic divinities, is the express tendency for each to have a family.

All of the divinities mentioned above are closely associated with horses: they either ride or are drawn in chariots across the sky mountain and arrive on earth in the same fashion. The number of horses is indeterminate but usually varies from two to five or more. This trait also confirms the close ties between Baltic and Indo-Iranian religions.

Although males form the majority of the sky gods, the chthonic (underworld) divinities are mostly female. In both Latvian and Lithuanian religions the earth is personified and called Earth Mother (Latvian Zemes māte, Lithuanian Žemyna). But the Lithuanians also have Earth Master (Žemėpatis). Latvians in general refer to mothers,

Lithuanians to masters. Zemes māte is the only deity in addition to Dievs who is originally responsible for human welfare. Based on the writings of the Roman historian Tacitus, it has been asserted that she is the mother of the other gods, but there is no support for this view in other sources. Under the influence of Christian–pagan syncretism, the Virgin Mary has assumed some of the functions of Zemes māte. Furthermore, some of these functions have been acquired and differentiated by various other later divinities, who, however, have not lost their original chthonic character. Thus, a deity of the dead has developed from Zemes māte, called in Latvian Smilšu māte ("Mother of the Sands"), Kapu māte ("Mother of the Graves"), and Veļu māte ("Mother of the Ghosts"). Libations and sacrifices were offered to Zemes māte. Such rituals were also performed in connection with the other divinities at a later stage of development. The fertility of the fields is also guaranteed by Jumis, who is symbolized by a double head of grain, and by various mothers, such as Lauka māte ("Mother of the Fields"), Linu māte ("Mother of the Flax"), and Mieža māte ("Mother of the Barley").

Forest and agricultural deities. A forest divinity, common to all Baltic peoples, is called in Latvian Meža māte and in Lithuanian Medeinė ("Mother of the Forest"). She again has been further differentiated into other divinities, or rather she was given metaphorical appellations with no mythological significance, such as Krūmu māte ("Mother of the Bushes"), Lazdu māte ("Mother of the Hazels"), Lapu māte ("Mother of the Leaves"), Ziedu māte ("Mother of the Blossoms"), and even Sēņu māte ("Mother of the Mushrooms"). Forest animals are ruled by the Lithuanian Žvėrinė opposed to the Latvian Meža māte.

The safety and welfare of the farmer's house is cared for by the Latvian Mājas gars ("Spirit of the House"; Lithuanian Kaukas), which lives in the hearth. Similarly, other farm buildings have their own patrons—Latvian Pirts māte ("Mother of the Bathhouse") and Rijas māte ("Mother of the Threshing House"); Lithuanian Gabjauja.

Gods of natural phenomena

Because natural phenomena and processes have often been raised to the level of divinities, there are a large number of beautifully described lesser mythological beings whose functions are either very limited or completely denoted by their names. Water deities are Latvian Jūras māte ("Mother of the Sea"), Ūdens māte ("Mother of the Waters"), Upes māte ("Mother of the Rivers"), and Bangu māte ("Mother of the Waves"; Lithuanian Bangpūtys), while atmospheric deities are Latvian Vēja māte ("Mother of the Wind"), Lithuanian Vėjopatis ("Master of the Wind"), Latvian Lietus māte ("Mother of the Rain"), Miglas māte ("Mother of the Fog"), and Sniega māte ("Mother of the Snow"). Even greater is the number of those beings related to human activities, but only their names are still to be found, for example Miega māte ("Mother of Sleep") and Tirgus māte ("Mother of the Market").

Goddess of destiny. Because of peculiarities of the source materials, it is difficult to determine whether the goddess of destiny, Laima (from the root word *laime,* meaning "happiness" and "luck"), originally had the same importance in Baltic religion as later, or whether her eminence is due to the specific historical circumstances of each of the Baltic peoples. In any case, a wide collection of material concerning Laima is available. The real ruler of human fate, she is mentioned frequently together with Dievs in connection with the process of creation. Although Laima determines a man's unchangeable destiny at the moment of his birth, he can still lead his life well or badly within the limits prescribed by her. She also determines the moment of a person's death, sometimes even arguing about it with Dievs.

The Devil. The Devil, Velns (Lithuanian Velnias), has a well-defined role, which is rarely documented so well in the folklore of other peoples. Besides the usual outer features, several characteristics are especially emphasized. Velns, for instance, is a stupid devil. In addition, the Balts are the only colonialized people in Europe who have preserved a large amount of folklore that in different variations and situations portrays the Devil as a German landlord. Another evil being is the Latvian Vilkacis, Lithuanian Vilkatas, who corresponds to the werewolf in the traditions of other peoples. The belief that the dead do not leave this world completely is the basis for both good and evil spirits. As good spirits the dead return to the living as invisible beings (Latvian *velis,* Lithuanian *vėlė*), but as evil ones they return as persecutors and misleaders (Latvian *vadātājs,* Lithuanian *vaidilas*).

PRACTICES, CULTS, AND INSTITUTIONS

Temples and other holy places. Archaeological excavations in the 20th century have indicated the existence of temples made of wood. The only remains of these temples are postholes. Such temples were circular, approximately 15 feet (five metres) in diameter, in the centre of which a statue of a god may have been erected. At present, however, the existence of such temples must be regarded only as conjecture within the realm of probability. On the other hand, the existence of open-air holy places or sites of worship among the Balts is confirmed by both the earliest historical documents and folklore. Such places were holy groves, called *alka* in Lithuanian. Later the word came to mean any holy place or site of worship (Lithuanian *alkvietė*). Considerable research has shown that the usual sites were little hills, where the populace gathered and sacrificed during holy festivals, all of which supports the idea that wooden buildings could have been built at these sites.

Sites of worship

Other holy places were also recognized. The most important of these appear to be bathhouses, whose function some researchers have compared to that of churches in Christianity. A large amount of evidence indicates that religious–magical rites, from birth ceremonies to funerals, were performed in such bathhouses. There are various opinions as to whether the so-called holy corner (*heilige Hinterecke*)—*i.e.,* the dark corner of a peasant's house in which a deity or patron lives—belongs to pre-Christian concepts or not. On the other hand, various places in the house proper, such as the hearth and the doorstep, were considered to be abodes of spirits. In general, the more important work sites each had its own guardian spirit. Sacrifices were performed at each spot to assure successful completion of work. Because they supplied the farmstead with water, streams and rivers were also especially important.

Religious personages. There is no reliable information that the Balts had a priestly class, let alone religious hierarchy. The 11th-century German historian Adam of Bremen, in describing conflicts between Christian missionaries and Latvians, said that "every house is filled with seers, augurers, and necromancers," which indicates that the Balts had sacral persons, probably the patriarchs of large extended families or heads of clans. As even 18th-century church inspection records show, the Christian church had great difficulty in curbing their influence, especially within their clans. Their religious functions were twofold. First, they were responsible for the welfare and means of existence of the people through the performance of appropriate rites both at work sites and during the holy festivals. Second, they assured that the proper procedure would be followed in rituals connected with the important occasions of human life, such as birth, marriage, and death. In the syncretistic amalgam of Christianity and the religion of the Balts, those persons were called sorcerers (*Zauberer*) and, according to church records, were treated by the Balts with the same reverence as bishops were treated by Christians.

Sacred times. Special rites evolved for the festivals of the summer solstice and the harvest, while other rites were used specifically for beginning various kinds of spring work. Such spring work included sending farm animals to pasture or horses to forage for the first time, plowing the first furrow, and starting the first spring planting. The birth of a child was especially noted; it usually took place in the bathhouse or some other quiet spot. Laima was responsible for both mother and child. One birth rite, called *pirtižas,* was a special sacral meal in which only women took part. Marriage rites were quite extensive and corresponded closely to similar Old Indian ceremonies. Fire and bread had special importance and were taken along to the house of the newly married couple. These

rites persisted until quite late and were to be seen even at the end of the 19th century, though in many cases only as games. In this connection, fire in general occupied a central place in Baltic religion. Considered holy, it was worshiped, and sacrifices were offered to it.

Death rites and customs

It seems unbelievable that even as late as 1377 and 1382, respectively, the Lithuanian king Algirdas and his brother Kęstutis could still be buried according to the old traditions in a Christian Europe; dressed in silver and gold, they were burned in funeral pyres together with their best possessions, horses, hunting dogs, birds, and weapons. In spite of a ban by the church and subsequent persecution, this rite still persisted in the 15th century. The tenacious preservation of this ancient Indo-European ritual casts light on other features of Baltic religion. Chronicles relate that Lithuanians, after losing a battle, joyfully committed suicide; this was also true of the widows of soldiers killed in battle. Such voluntary immolation and the articles buried with the dead are evidence of a belief in life after death. It is said that at the funeral of a nobleman his companions threw lynx and bear claws into the fire to aid his climb up the mountain to God, an indication of Christian influence. Archaeological excavations have also yielded evidence of fire funeral rites: the bones of humans and animals, metal jewelry, and weapons found at the sites of the funeral pyres.

By courtesy of Istorinis Muziejus, Kaunas, Lithuania



Decorated horse skull used in Baltic funeral rites. In the Kaunas State Historical Museum, Lithuania.

In funeral rites several different phases are discernible during the period between death and burning. The deceased was laid out in his house for a longer or shorter period depending on his social position and the size of his estate. During this time a meal lasting several days was held for the deceased's relatives and friends. In the course of the festivities the participants conducted fights on horseback. Lamentations, leave-takings, and praises of the deceased, as well as wishes for a safe journey to the world of the dead, accompanied the corpse on the way to the funeral pyre. In spite of persecution by the church, the tradition of lamentation has lasted until modern times, though in a somewhat modified form. One of the peculiarities of Baltic funeral rites was their similarity to wedding ceremonies. The corpse and a partner selected from the living were dressed in elaborate wedding costumes, wedding songs were sung, and dancing took place. The basis of these ceremonies was the belief that the dead anticipate a new companion with the same joy as the living do a new in-law. The corpse's living partner was a symbolical substitute for the new comrade awaited by the dead.

The use of living people to represent symbolically the companions of the dead in funerary practices suggests a dominant concept in Baltic religious thought, namely, that the boundary between the worlds of the dead and the living was not real. The dead continued to live invisibly and were present at all important occasions. A place was set for them at the festival table and no one else might sit there. The extensive practice of feeding the dead was a consequence of the concept that the living were responsible for their welfare. Originally, their food must have been placed at the hearth. In later development, meals for the dead were also placed in other buildings, such as the threshing house or the bathhouse. Under the influence of Christianity, these living dead (Latvian *velis*, Lithuanian *vėlė*) have been confused with the Devil. A widespread view was that the souls of the dead dwell in the *zalktis* (Latvian; Lithuanian *žaltys*; "green snake"); thus special care was taken in its feeding. But the *zalktis* was also closely associated with fertility and sexual symbolism.

CONCLUSION

Three main characteristics are discernible in Baltic religion. First, it is a typical astral religion in which the personified sky and main heavenly bodies play a major role. Saule, Mēness, Auseklis, and other gods have their own traits, frequently based on counterparts in nature. Although they are all related as one family, their roles within the family are varied. Depending on the cult or the plot of the myth, each divinity can assume various functions; a religious person, in general, does not experience such fluctuations as a contradiction. The second main characteristic is the personification of happiness, luck, and fate in Laima, who has assumed the role of a goddess of destiny. Because happiness is not an external, datable event, other gods besides Laima can help determine happiness in human life. The differentiation of Laima's functions has led to the establishment of some of her functions as independent entities with sometimes a poetic, sometimes a religious, meaning. The concept of destiny in Baltic religion has not, however, resulted in passive resignation or quietism but rather full exploitation of opportunities within the limits set by it. The third characteristic is the fertility cult. Here the primary force is the personified earth, called Mother, with all her functions and characteristics. It must be understood that the concept of a fertility cult entails a wider meaning, that of the assurance of human welfare in general.

Three main characteristics

These three main typological traits hardly describe Baltic religion in all of its details and nuances. The religion can also be analyzed as having two strata: one, expressed in the above three features, can be called the stable surface layer; the second, visible below the first, contains only the outlines of undifferentiated, fluid mythological and religious beings that, because of their vague character, appear in various guises and have no stable role. They are the countless house, field, and wood spirits of the nature myths.

Baltic religion, typologically, is an agricultural religion, and it is useless to speculate whether any other basis—such as nomadism, hunting, or fishing—can be found for it, because no information regarding such possibilities can be derived from any source. The amorphous agricultural clan defines the nature of Baltic religion. The farmer's gods are also farmers, though they live in great glory on their farmsteads on the sky mountain, from which they descend to help their lesser image—man. If necessary, Dievs, Saule, and Laima dress themselves in farmer's clothes and walk his fields with him. This religion does not recognize contemplation or mysticism but rather exhibits a healthy rationalism. Just as the gods are part of the cosmic order and are responsible for its maintenance, so humans obey it and become part of the divine rhythm of life set by the gods. In this way, humans cross the boundary that otherwise separates them from the world of the gods. Various specific historical circumstances explain why the Balts, in their language as well as in their religion, have preserved many elements undoubtedly belonging to the oldest phase of Indo-European religion. (H.Bi.)

Slavic religion

Slavic religion is understood here to include only the relevant beliefs and practices of the ancient Slavic peoples of eastern Europe. Slavs are usually subdivided into East Slavs (Russians, Ukrainians, and Belorussians), West Slavs (Poles, Czechs, Slovaks, and Lusatians [Sorbs]), and South Slavs (Serbs, Croats, Slovenes, Macedonians, and Bulgars).

In antiquity the Slavs were perhaps the most numerous branch of the Indo-European family of peoples. The very late date at which they came into the light of recorded history (even their name does not appear before the 6th century AD) and the scarcity of relics of their culture make serious study of them a difficult task. Sources of information about their religious beliefs are all late and by Christian hands.

SLAVIC WORLDVIEW

Socially the Slavs were organized as exogamous clans (based on marriages outside blood relationship) or, more properly, as sibs (groups of lineages with common ancestry) since marriage did not cancel membership in the clan of one's birth—a type of organization unique among Indo-European peoples. The elected chief did not have executive powers. The world had been created, in the Slavic view, once and for all, and no new law ought to modify the way of life transmitted by their ancestors. Since the social group was not homogeneous, validity and executive power were attributed only to decisions taken unanimously in an assembly, and the deliberations in each instance concerned only the question of conformity to tradition. Ancient Slavic civilization was one of the most conservative known on earth.

According to a primitive Slavic belief, a forest spirit, *leshy,* regulates and assigns prey to hunters. Its food-distributing function may be related to an archaic divinity. Though in early times the *leshy* was the protector of wild animals, in later ages it became the protector of flocks and herds. In early 20th-century Russia, if a cow or a herdsman did not come back from pasture, the spirit was offered bran and eggs to obtain a safe return.

Varieties of spirits

Equally ancient is the belief in a tree spirit that enters buildings through the trunks of trees used in their construction. Every structure is thus inhabited by its particular spirit: the *domovoy* in the house, the *ovinnik* in the drying-house, the *gumenik* in the storehouse, and so on. The belief that either harmful or beneficial spirits dwell in the posts and beams of houses is still alive in the historic regions of Bosnia and Slovenia and the Poznań area of west central Poland. Old trees with fences around them are objects of veneration in Serbia and Russia and among the Slavs on the Elbe River. In 19th-century Russia a chicken was slaughtered in the drying house as a sacrifice to the *ovinnik.* This vegetal spirit is also present in the sheaf of grain kept in the "sacred corner" of the dwelling under the icon and venerated along with it, and also in noncultivated plant species that are kept in the house for propitiation or protection, such as branches of the birch tree and bunches of thistle. Such practices evidence the preagrarian origin of these beliefs. Similar to the *leshy* are the field spirit (*polevoy*), and, perhaps, the water spirit (*vodyanoy*). Akin to the *domovoy* are the spirits of the auxiliary buildings of the homestead.

MYTHOLOGY

Cosmogony. A myth known to all Slavs tells how God ordered a handful of sand to be brought up from the bottom of the sea and created the land from it. Usually, it is the Devil who brings up the sand; in only one case, in Slovenia, is it God himself. This earth-diver myth is diffused throughout practically all of Eurasia and is found in ancient India as well.

The 12th-century German missionary Helmold of Bosau recorded in *Chronica Slavorum* (*Chronicle of the Slavs*) his surprise in encountering among the Slavs on the Baltic a belief in a single heavenly God, who ignored the affairs of this world, having delegated the governance of it to certain spirits begotten by him. This is the only instance in which the sources allude to a hierarchy of divinities, but its centre is empty. The divinity mentioned by Helmold is a *deus otiosus; i.e.,* an inactive god, unique in the mythology of the Indo-European peoples. Such a deity is, however, also found among the Volga Finns, the Ugrians, and the Uralians.

Helmold's *deus otiosus*

Principal divine beings. Common to this Eurasian area is another divinity, called by Helmold and in the *Knytlinga saga* (a Danish legend that recounts the conquest of Arkona through the efforts of King Valdemar I of Denmark against the pagan and pirate Slavs) Zcerneboch (or Chernobog), the Black God, and Tiarnoglofi, the Black Head (Mind or Brain). The Black God survives in numerous Slavic curses and in a White God, whose aid is sought to obtain protection or mercy in Bulgaria, Serbia, and Pomerania. This religious dualism of white and black gods is common to practically all the peoples of Eurasia.

The Kiev Chronicle (*Povest vremennykh let*)—a 12th- to 13th-century account of events and life in the Kievan state—enumerates seven Russian pagan divinities: Perun, Volos, Khors, Dazhbog, Stribog, Simargl, and Mokosh. A Russian glossary to the 6th-century Byzantine writer John Malalas' *Chronographia* mentions a Svarog, apparently the son of Dazhbog. Of all these figures only two, Perun and Svarog, are at all likely to have been common to all the Slavs. In Polish, *piorun,* the lightning, is derived from the name of Perun, and not vice versa. In the province of Wielkopolska the expression *do pierona*—meaning "go to the Devil"—has been recorded. In the expression, *pieron/piorun* is no longer the lightning but the being who launches it. Uncertain or indirect traces of Perun are also encountered among the Carpathians and in Slovenia and Serbia. The lightning-wielding Perun cannot be considered the supreme god of the Slavs but is rather a spirit to whom was given the governance of the lightning.

In Estonia the prophet Elijah is considered to be the successor to Ukko, the ancient spirit of lightning. Similarly, the prophet Elijah replaces Elwa in Georgia and Zeus in Greece. It is therefore probable that, among the Slavs also, Elijah is to be considered a successor of Perun. According to a popular Serbian tradition, God gave the lightning to Elijah when he decided to retire from governing the world. The Serbian story agrees with Helmold's description of the distribution of offices by an inactive God. Elijah is a severe and peevish saint. It is rare that his feast day passes without some ill fortune. Fires—even spontaneous combustion—are blamed on him.

A similar complex may be seen if the Slavic Perun is equated with Perkūnas, the lightning deity of the Lithuanians. In Latvia, creatures with black fur or plumage were sacrificed to Pērkons, as they were to the fire god Agni in ancient India. Such deities are therefore generic deities of fire, not specifically celestial and even less to be regarded as supreme. Scholarly efforts to place Perun at the centre of Slavic religion and to create around him a pantheon of deities of the Greco-Roman type cannot yield appreciable results. Russian sources treat Svarog, present as Zuarasici among the Liutici of Rethra (an ancient locality in eastern Germany), as a god of the drying-house fire. But the Belorussians of Chernigov, when lighting the drying-house fire, invoke Perun and not Svarog, as if Svarog (apparently from *svar,* "litigation" or "dispute," perhaps referring to the friction between the pieces of wood used to produce ignition) were an appellation of Perun.

Folk conceptions. In a series of Belorussian songs a divine figure enters the homes of the peasants in four forms in order to bring them abundance. These forms are: *bog* ("god"); *sporysh,* anciently an edible herb, today a stalk of grain with two ears, a symbol of abundance; *ray* ("paradise"); and *dobro* ("the good"). The word *bog* is an Indo-Iranian word signifying riches, abundance, and good fortune. *Sporysh* symbolizes the same concept. In Iranian *ray* has a similar meaning, which it probably also had in Slavic languages before it acquired the Christian meaning of paradise. *Bog,* meaning "riches," connotes grain. The same concept is also present in Mordvinian *pa* and *riz*—where their provenance is certainly Iranian. Among the Mordvins, Paz, like the Slavic Bog, enters into the homes bringing abundance. The adoption of the foreign word *bog* probably displaced from the Slavic languages the Indo-

European name of the celestial God, Deivos (Ancient Indian Deva, Latin Deus, Old High German Ziu, etc.), which Lithuanian, on the other hand, has conserved as Dievas.

Worship of celestial bodies

Among the heavenly bodies the primary object of Slavic veneration was the moon. The name of the moon is of masculine gender in Slavic languages (Russian *mesyats;* compare Latin *mensis*). The word for sun (Russian *solntse*), on the other hand, is a neuter diminutive that may derive from an ancient feminine form. In many Russian folk songs a verb having the sun as its subject is put in the feminine form, and the sun is almost always thought of as a bride or a maiden.

It is to the moon that recourse is had to obtain abundance and health. The moon is saluted with round dances and is prayed to for the health of children. During lunar eclipses, weapons are discharged at the monsters who are said to be devouring the moon, and weeping and wailing express the sharing of the moon's sufferings. In Serbia the people have always envisioned the moon as a human being. Such appellations as father and grandfather are customarily applied to the moon in Russian, Serbo-Croatian, and Bulgarian folk songs. At Risano (modern-day Risan, Yugos.) in the days of the 19th-century writer Vuk Karadžić—the father of modern Serbian literature—it was said of a baby four months old that he had four grandfathers. In Bulgaria the old people teach small children to call the moon Dedo Bozhe, Dedo Gospod ("Uncle God, Uncle Lord"). Ukrainian peasants in the Carpathians openly affirm that the moon is their god and that no other being could fulfill such functions if they were to be deprived of the moon. In two Great Russian supplications the sickle moon is invoked as "Adam"—the final phase of a fully developed moon worship in which the moon becomes the progenitor of the human family.

PRACTICES, CULTS, AND INSTITUTIONS

Places of worship. Though the idols of which the Russian chronicles speak appear to have been erected out-of-doors, the German chronicles provide detailed descriptions of enclosed sacred places and temples among the Baltic Slavs. Such enclosures were walled and did not differ from profane fortifications—areas usually of triangular shape at the confluence of two rivers, fortified with earthwork and palisades, especially on the access side. The fortifications intended for religious purposes contained wooden structures including a cell for the statue of a god, also made of wood and sometimes covered in metal. These representations, all anthropomorphic, very often had supernumerary bodily parts: seven arms, three or five heads (Trigelavus, Suantevitus, and Porenutius). The temples were in the custody of priests, who enjoyed prestige and authority even in the eyes of the chiefs and received tribute and shares of military booty. Human sacrifices, including eviscerations, decapitations, and trepanning, had a propitiatory role in securing abundance and victory. One enclosure might contain up to four temples; those at Szczecin (Stettin), in northwestern Poland, were erected in close proximity to each other. They were visited annually by the whole population of the surrounding district, who brought with them oxen and sheep destined to be butchered. The boiled meat of the animals was distributed to all the participants without regard to sex or age. Dances and plays, sometimes humorous, enlivened the festival.

Temple ceremonies

Communal banquets and related practices. The custom of communal banquets has been preserved into modern times in Russia in the *bratchina* (from *brat,* "brother"), in the *mol'ba* ("entreaty" or "supplication"), and in the *kanun* (a short religious service); in the Serbian *slava* ("glorification"); and in the *sobor* ("assembly") and *kurban* ("victim" or "prey") of Bulgaria. Formerly, communal banquets were also held by the Poles and the Polabs (Elbe Slavs) of Hannover. In Russia the love feasts are dedicated to the memory of a deceased person or to the patron saint of the village and in Serbia to the protecting saint from whom the *rod* or *pleme* ("clan") took its name. Scholars no longer have any doubts of the pre-Christian nature of these banquets. The Serbian *slava* is clearly dedicated to a saint held to be the founder of the clan. These saints are patrons or founders and are all men who have died. When the Serbs celebrate the *slava* of the prophet Elijah or of the archangel Michael, they do not set out the "dead man's plate" (the *koljivo,* boiled wheat), because Elijah and Michael are not considered dead. In certain localities in Serbia, even the women given in marriage to another clan, the so-called *odive,* have to be present at the *slava.* They return with their children (according to the ancient matrilineal conception of the offspring), but not with their husbands, who belong to another clan and celebrate another *slava.* More akin to the ancient pagan feasts of the Baltic is the Serbian *seoska slava,* or "*slava* of the village," in which the whole community participates and consumes in common the flesh of the victims prepared in the open air. Such feasts are votive. In Russia sometimes the animals (or their flesh) are first brought into the church and perfumed with incense. Even at the beginning of the 20th century, there were small villages in Russia where cattle were butchered only on the occasion of these festivities, three or four times a year. *The Homily of Opatoviz* (attributed to Herman, bishop of Prague) of the 10th–11th centuries emphatically condemns the love feasts as well as the veneration of statues and Slavic worship of the dead and veneration of saints as if they were gods. As in the Christian era the saints entered the line of ancestors, so perhaps in pagan antiquity ancient divinities (Perun, Svarog) were taken over as tribal progenitors. The Slavs did not record genealogies, and the founders of their clans were mainly legendary. The social unit sought to assure for itself the favour of powerful figures of the past, even of more than one, representing them in several forms on the same pillar or giving to their statues supernumerary bodily parts that would express their superhuman powers. A hollow bronze idol, probably ancient Russian, was found at Ryazan, Russia. The idol has four faces with a fifth face on its breast.

The eastern Finns and the Ugrians venerated their dead in the same way, similarly representing them as polycephalic (multiple-headed), and also held communal banquets in their honour. Wooden buildings (the so-called *continae*) in which the faithful Baltic Slavs used to assemble for amusement, to deliberate, or to cook food have been observed in the 20th century among the Votyaks, the Cheremis, and the Mordvins but especially among the Votyaks. Such wooden buildings also existed sparsely in Slavic territory in the 19th century, in Russia, in Ukraine, and in various locales among the South Slavs.

If it is supposed that, as among the Finns and the Ugrians, each clan venerated its own divine ancestor in a separate building, this would explain why many sacred enclosures would contain more than one *contina*—three at Carentia (the island of Garz at the mouth of the Oder River) and four at Szczecin.

The custom of second interment

The system of idolatry of the Baltic area was essentially manistic (pertaining to worship of ancestors). It is not irrelevant that until the 19th century there survived here and there throughout the Danubian-Balkan region the custom of reopening graves three, five, or seven years after interment, taking out the bones of the corpses, washing them, wrapping them in new linen, and reinterring them. Detailed descriptions of this procedure have come particularly from Macedonia and Slovenia. Among East and West Slavs only faint echoes of the custom of a second interment survive in folk songs. In the former *guberniya* (province) of Vladimir, east of Moscow, as late as 1914, when a grave was to be dug, a piece of cloth was taken along with which to wrap the bones of any earlier corpse that might be unearthed in the process of digging. Such corpses would then be reinterred with the newly deceased. In protohistoric times the tumuli (mounds) of the mortuaries of the Krivichi, a populous tribe of the East Slavs of the northwest, the so-called long kurgans (burial mounds), contained cinerary urns buried in the tumulus together and all at one time. Such a practice could occur only as the consequence of collective and simultaneous cremation. There must, therefore, have existed a periodic cremation season or date, as for the opening of the tombs in Macedonia and as has been verified elsewhere in comparing the South Asian areas of second interment, in preparation for which the corpses are temporarily ex-

humed. The cremations by the Krivichi are of exhumed bones. In the Volga region today the Mordvins still burn the disinterred bones of the dead in the flames of a "living fire" ignited by friction.

Considering the religious past of the Slavs, it is not surprising that manism was strong enough to epitomize and overwhelm all or practically all of their religious views. The seasonal festivals of the Slavs turn out to be almost entirely dedicated to the dead, very often without the participants realizing it, as in the case of the Koljada (Latin Kalendae)—the annual visit made by the spirits of the dead, under the disguise of beggars, to all the houses in the village. It is possible that the bones of the disinterred were kept for a long period inside the dwellings, as is still sometimes done in the Tyrol of Austria, and that the sacred corner—now occupied by the icon—was the place where they were kept.

The spirits of the departed are not only venerated but also feared, especially the spirits of those who were prematurely deprived of life and its joys. It is believed that such spirits are greedy for the good things thus lost and that they make attempts to return to life—to the peril of the living. They are the prematurely dead, the so-called unclean dead. Particularly feared are maidens who died before marriage and are believed to be addicted to the kidnapping of bridegrooms and babies. One annual festival in particular, the Semik (seventh Thursday after Easter) was dedicated to the expulsion of these spirits. They are called *rusalki* in Russia, *vile* or *samovile* in Serbo-Croatia and Bulgaria.

The belief in vampires

The dead person who does not decompose in the grave becomes a vampire, a word and concept of Slavic origin. To save the living from a vampire's evil deeds, it is necessary to plant a stake in the grave so that it passes through the heart of the corpse or else to exhume the corpse and burn it. Since the classes of unclean dead are believed to have been constantly increasing (in Macedonia, for example, it is believed that all those born in the three months between Christmas and Lady Day are unclean), then all of the dead—once objects of veneration and piety—will at some point be in danger of rancor, fear, and eventual disregard. A Christian clergy that has lent its presence at the exhumation and destruction of vampires has thereby contributed unwittingly to the preservation of this last phase of Slavic paganism into modern times.

There are other rites associated with second interment of which the Slavs have forgotten the purpose, such as the cemetery pyres—fires lit on top of the tombs—or the assiduous watering of graves. In Polynesia and South America where second interment is practiced, these same acts have the purpose of fostering decomposition of the corpses in order to hasten exhumation.

Numerous other ritual acts are performed by the Slavs, for the most part related to this complex of beliefs. In 19th-century Russia, if a man encountered the procession of naked women who were plowing a furrow around the village at night in order to protect it from an epidemic, he was inevitably killed. It was a chthonic (underworld) being to which, in those same times, human sacrifices were offered in Russia (more rarely in Poland and Bulgaria), since the victims were often buried alive. In most cases they were either voluntary victims or chosen by lot from among the devotees. Since such acts were punished by the law of the state, the sacrifices were performed in secrecy and are difficult to document. (E.G.)

Greek religion

Greek religion, comprising the beliefs of the ancient Hellenes about gods and their relationship with humanity, lasted in its developed form for more than a thousand years, from the time of Homer (probably 9th or 8th century BC) to the reign of the emperor Julian (4th century AD), though its origins may be traced to the remotest eras. During that period its influence spread as far west as Spain, east to the Indus River, and throughout the Mediterranean world. Its effect was most marked on the Romans, who identified their deities with the Greek. Under Christianity, Greek heroes and even deities survived as saints, while the rival madonnas of southern European communities reflected the independence of local cults. The rediscovery of Greek literature during the Renaissance and, above all, the novel perfection of classical sculpture produced a revolution in taste that had far-reaching effects on Christian religious art. The most striking characteristic of Greek religion was the belief in a multiplicity of anthropomorphic deities, coupled with a minimum of dogmatism.

The student of Greek religion is naturally concerned to know what the Greeks believed about their gods. They had numerous beliefs, but the sole requirement was to believe that the gods existed and to perform ritual and sacrifice, through which the gods received their due. To deny the existence of a deity was to risk reprisals, from the deity or from other mortals. The list of avowed atheists is brief. But if a Greek went through the motions of piety, he risked little, since no attempt was made to enforce orthodoxy, a religious concept almost incomprehensible to the Greeks. The Greeks had no word for religion itself, the closest approximations being *eusebeia* ("piety") and *threskeia* ("cult"). The large corpus of myths concerned with gods, heroes, and rituals embodied the worldview of Greek religion and remains its legacy. It should be noted that the myths varied over time and that, within limits, a writer—*e.g.*, a Greek tragedian—could vary a myth in order to change not only the role played by the gods in it but also the evaluation of the gods' actions. From the later 6th century BC onward, myths and gods were subject to rational criticism on ethical or other grounds. In these circumstances it is easy to overlook the fact that most Greeks "believed" in their gods in roughly the modern sense of the term and that they prayed in a time of crisis not merely to the "relevant" deity but to any deity on whose aid they had established a claim by sacrifice. To this end, each Greek polis had a series of public festivals throughout the year that were intended to ensure the aid of all the gods who were thus honoured. They reminded the gods of services rendered and asked for a quid pro quo. In crises in particular the Greeks, like the Romans, were often willing to add deities borrowed from other cultures.

It is frequently difficult to obtain evidence of Greek religious practice, not only within the mystery cults but also more generally. In the latter case, the reason is not one of secrecy; the Greeks simply did not anticipate a posterity that would be different from themselves. Religious practices were universally known—as were such everyday activities as sailing triremes and holding assemblies—and it was not deemed necessary to record these things. It should be remembered that Pausanias, the most important source for a number of topics, was writing in the 2nd century AD, and that even by the 5th century BC the meaning and origins of some of the practices he described were evidently unknown.

HISTORY

The roots of Greek religion. The study of a religion's history includes the study of the history of those who espoused it, together with their spiritual, ethical, political, and intellectual experiences. Greek religion as it is currently understood probably resulted from the mingling of religious beliefs and practices between the incoming Greek-speaking peoples who arrived from the north during the 2nd millennium BC and the indigenous inhabitants whom they called "Pelasgi." The incomers' pantheon was headed by the Indo-European sky god variously known as Zeus (Greek), Dyaus (Indian), or Jupiter (Roman Diespater). But there was also a Cretan sky god, whose birth and death were celebrated in rituals and myths quite different from those of the incomers. The incomers applied the name of Zeus to his Cretan counterpart. In addition, there was a tendency, fostered but not necessarily originated by Homer and Hesiod, for major Greek deities to be given a home on Mount Olympus. Once established there in a conspicuous position, the Olympians came to be identified with local deities and to be assigned as consorts to the local god or goddess. An unintended consequence (since the Greeks were monogamous) was that Zeus in particular became markedly polygamous. (Zeus already had a consort when he arrived in the Greek world and

Greek and Pelasgian deities

took Hera, herself a major goddess in Argos, as another.) Hesiod used—or sometimes invented—the family links among the deities, traced out over several generations, to explain the origin and present condition of the universe. At some date, Zeus and other deities were identified locally with heroes and heroines from the Homeric poems and called by such names as Zeus Agamemnon. The Pelasgian and the Greek strands of the religion of the Greeks can sometimes be disentangled, but the view held by some scholars that any belief related to fertility must be Pelasgian, on the grounds that the Pelasgi were agriculturalists while the Greeks were nomadic pastoralists and warriors, seems somewhat simplistic. Pastoralists and warriors certainly require fertility in their herds—not to mention in their own number. In cult, Athena, a warrior goddess and patron of the arts and crafts and a prominent Olympian, presided also over fertility festivals. The citizens prayed to her for all good things; the fertility of field, flock, and citizen was as essential to the well-being of the polis as its victory in war.

The Archaic period. Sometime before the Homeric poems took their present form, the orgiastic cult of the nature divinity Dionysus reached Greece, traditionally from Thrace and Phrygia. Because the god's name is Greek, it has been suggested that his worship represents not a novelty but a reversion to Mycenaean religion. His devotees, armed with *thyrsoi* (wands tipped with a pine cone and wreathed with vine or ivy) and known as maenads (literally "mad women"), were reputed to wander in *thiasoi* (revel bands) about mountain slopes, such as Cithaeron or Parnassus; the practice persisted into Roman imperial times. They were also supposed, in their ecstasy, to practice the *sparagmos,* the tearing of living victims to pieces and feasting on their raw flesh (*ōmophagia*). While such behaviour continued in the wild, in the cities—in Athens, at any rate—the cult of Dionysus was tamed before 500 BC. Tragedy developed from the choral song of Dionysus.

The cult of Dionysus

In the 7th and 6th centuries BC "tyrants" (monarchs whose position was not derived from heredity) seized power in many poleis. Some of them, such as Peisistratus in Athens, were nobles themselves and rose to power by offering the poor defense against the rest of the nobility. Once established, Peisistratus built temples and founded or revived festivals. At this time, too, the earliest references to the Eleusinian Mysteries appear. The Mysteries offered a more personal, less distant relationship with the divine than did most of the Olympians. There was no Eleusinian way of life. On one or two occasions (depending on the grade they wished to attain) the initiates went to Eleusis; what they saw there in the place of initiation sufficed to ensure them a life after death that was much more "real" than the Olympian belief that the dead were witless ghosts.

The Classical period. During the 6th century BC the rationalist thinking of Ionian philosophers had offered a serious challenge to traditional religion. At the beginning of the 5th century, Heracleitus of Ephesus and Xenophanes of Colophon heaped scorn on cult and gods alike.

The Sophists, with their relentless probing of accepted values, continued the process. Little is known of the general success of these attacks in society as a whole. The Parthenon and other Athenian temples of the late 5th century proclaim the taste and power of the Athenians rather than their awe of the gods; but it is said that after the completion of Phidias' chryselephantine Athena on the Acropolis, the old olive-wood statue of Athena, aesthetically no match for Phidias' work, continued to receive the worship of most of the citizens. Antiquity evoked awe; some of the most revered objects in Greece were antique and aniconic figures that bore the name of an Olympian deity.

Festivals were expressive of religion's social aspect and attracted large gatherings (*panēgyreis*). Mainly agrarian in origin, they were seasonal in character, held often at full moon and on the 7th of the month in the case of Apollo, and always with a sacrifice in view. Many were older than the deity they honoured, like the Hyacinthia and Carneia in Laconia, which were transferred from local heroes to Apollo. The games were a special festival, sometimes part of other religious events. Some festivals of Athens were performed on behalf of the polis and all its members. Many of these seem to have been originally the cults of individual noble families who came together at the *synoikismos,* the creation of the polis of Athens from its small towns and villages. The nobles continued to furnish the priests for these cults, but there was, and could be, no priestly class. There were no "priests of the gods," or even priests of an individual god; one became a priest of one god at one temple. Except for these public festivals, anyone might perform a sacrifice at any time. The priest's role was to keep the temple clean; he was usually guaranteed some part of the animal sacrificed. A priesthood offered a reasonably secure living to its incumbent.

Popular religion flourished alongside the civic cults. Peasants worshiped the omnipresent deities of the countryside, such as the Arcadian goat-god Pan, who prospered the flocks, and the nymphs (who, like Eileithyia, aided women in childbirth) inhabiting caves, springs (Naiads), trees (Dryads and Hamadryads), and the sea (Nereids). They also believed in nature spirits such as Satyrs and Sileni and equine Centaurs. Among the more popular festivals were the rural Dionysia, which included a phallus pole; the Anthesteria, when new wine was broached and offerings were made to the dead; the Thalysia, a harvest celebration; the Thargelia, when a scapegoat (*pharmakos*) assumed the communal guilt; and the Pyanepsia, a bean feast in which boys collected offerings to hang on the *eirestōne* ("wool pole"). Women celebrated the Thesmophoria in honour of Demeter and commemorated the passing of Adonis with laments and miniature gardens, while images were swung from trees at the Aiora to get rid of an ancient hanging curse. Magic was widespread. Spells were inscribed on lead tablets. Statues of Hecate, goddess of witchcraft, stood outside dwellings, while Pan's image was beaten with herbs in time of meat shortage.

The Hellenistic period. Greek religion, having no creed, did not proselytize. In the heyday of the polis, the Greek religion was spread by the founding of new poleis, whose colonists took with them part of the sacred fire from the hearth of the mother city and the cults of the city's gods. ("Heroes," being essentially bound to the territory in which they were buried, had to be left behind.) There was a tendency for Greeks to identify the gods of others with their own, often at a superficial level. So the virgin Artemis was identified with the chief goddess of Ephesus, a fertility deity. After Alexander the Great had created a political world in which the poleis were engulfed by large kingdoms, those deities who were not too closely linked with a particular place became more prominent. Mystery cults, which offered a personal value to the individual in a large and indifferent world, also flourished. The Cabeiri of Samothrace were patronized by both the Ptolemies and the Romans, while the Egyptian cults of Isis and Sarapis, in a Hellenized form, spread widely. Rulers sometimes officially invited new gods to settle in times of crisis, in the hope that they would strive on their new worshipers' behalf against their mortal foes: a mode of religious thought that flourished at least until the days of the Roman emperor Constantine. Those novel cults that seemed likely to pose a threat to public order, on the other hand, were suppressed by the Romans. The Senate destroyed the Bacchic cult in Italy in 186 BC for the same reasons as Trajan gave to Pliny for his treatment of the Christians: Any cult in which men and women, bond and free, could participate and meet together—a most unusual circumstance in the ancient world—had dangerous political implications.

BELIEFS, PRACTICES, AND INSTITUTIONS

The gods. The early Greeks personalized every aspect of their world, natural and cultural, and their experiences in it. The earth, the sea, the mountains, the rivers, custom-law (*themis*), and one's share in society and its goods were all seen in personal as well as naturalistic terms. When Achilles fights with the River in the *Iliad,* the River speaks to Achilles but uses against him only such weapons as are appropriate to a stream of water. In Hesiod, what could be distinguished as anthropomorphic deities and personalizations of natural or cultural phenomena both beget and are begotten by each other. Hera is of the first type—god-

dess of marriage but not identified with marriage. Earth is evidently of the second type, as are, in a somewhat different sense, Eros and Aphrodite (god and goddess of sexual desire) and Ares (god of war). These latter are personalized and anthropomorphized, but their worshipers may be "filled" with them. Some deities have epithets that express a particular aspect of their activities. Zeus is known as Zeus Xenios in his role as guarantor of guests. It is possible that Xenios was originally an independent deity, absorbed by Zeus as a result of the Olympocentric tendencies of Greek religion encouraged by the poems of Homer and Hesiod.

In Homer the gods constitute essentially a super-aristocracy. The worshipers of these gods do not believe in reward or punishment after death; one's due must come in this life. Every success shows that the gods are well disposed, for the time being at least; every failure shows that some god is angry, usually as a result of a slight, intended or unintended, rather than from the just or unjust behaviour of one mortal to another. The Greeks knew what angered their mortal aristocracy and extrapolated from there. Prayer and sacrifice, however abundant, could not guarantee that the gods would grant success. The gods might prefer peace on Olympus to helping their worshipers. These are not merely literary fictions; they reflect the beliefs of people who knew that though it might be necessary to offer prayer and sacrifice to the gods, it was not sufficient. Greek and Trojans sacrificed to their gods to ensure divine support in war and at other times of crisis. It was believed that Zeus, the strongest of the gods, had favoured the Trojans, while Hera had favoured the Greeks. Yet Troy fell, like many another city. The Homeric poems here offer an explanation for something that the Greek audience might at any time experience themselves.

There is no universal determinism in Homer or in other early writers. *Moira* ("share") denotes one's earthly portion, all the attributes, possessions, goods, or ills that together define one's position in society. Homeric society is stratified, from Zeus to the meanest beggar. To behave in accordance with one's share is to behave in accordance with one's status; and even a beggar may go beyond his share, though he is likely to be punished for it. Zeus, the most powerful entity in Homer's universe, certainly has the power to go beyond his share; but if he does so, the other gods "will not approve." And Zeus may be restrained, unless he feels that his "excellence," his ability to perform the action, is being called into question. Then he may insist on displaying his excellence, as do Achilles and Agamemnon, whose values coincide with those of Zeus in such matters.

Stratification of society

In Homer, *hērōs* denotes the greatest of the living warriors. The cults of these mighty men developed later around their tombs. Heroes were worshiped as the most powerful of the dead, who were able, if they wished, to help the inhabitants of the polis in which their bones were buried. Thus, the Spartans brought back the bones of Orestes from Tegea. Historical characters might be elevated to the status of heroes at their deaths. During the Peloponnesian War, the inhabitants of Amphipolis heroized the Spartan general Brasidas, who had fought so well and bravely and died in their defense. It is power, not righteousness, that distinguishes the hero; it is the feeling of awe before the old, blind Oedipus that stimulates the Thebans and the Athenians to quarrel over his place of burial. Since they are the mightiest of the dead, heroes receive offerings suitable for chthonic deities.

Cosmogony. Of several competing cosmogonies in archaic Greece, Hesiod's *Theogony* is the only one that has survived in more than fragments. It records the generations of the gods from Chaos (literally, "Yawning Gap") through Zeus and his contemporaries to the gods who had two divine parents (*e.g.*, Apollo and Artemis, born of Zeus and Leto) and the mortals who had one divine parent (*e.g.*, Heracles, born of Zeus and Alcmene). Hesiod uses the relationships of the deities, by birth, marriage, or treaty, to explain why the world is as it is and why Zeus, the third supreme deity of the Greeks, has succeeded in maintaining his supremacy—thus far—where his predecessors failed. Essentially, Zeus is a better politician and has the balance of power, practical wisdom, and good counsel on his side. (Whether Hesiod or some earlier thinker produced this complex nexus of relationships, with which Hesiod could account for virtually anything that had occurred or might occur in the future, the grandeur of this intellectual achievement should not be overlooked.)

Man. In the period in Greece between Homer and about 450 BC the language of relationships between god and god, man and god, and human beings of lower status with human beings of higher status was the same. The deities remained a super-aristocracy. There was a scale of "power-and-excellence" on which the position of every human being and every deity could be plotted. Both god and man were likely to resent any attempt of an inferior to move higher on the scale. It constituted *hubris* ("overweening pride") for a Greek *hēros* to claim that he would have a safe voyage whether or not the gods were willing; it was likewise *hubris* for Electra to presume to criticize the behaviour of her mother Clytemnestra.

A further reason for Olympian disapproval, only marginally present in Homer, was the pollution caused by certain actions and experiences, such as childbirth, death, or having a bad dream. The divine world of the Greeks was bisected by a horizontal line. Above that line were the Olympians, gods of life, daylight, and the bright sky; below it were the chthonic (underworld) gods of the dead and of the mysterious fertility of the earth. The Olympians kept aloof from the underworld gods and from those who should be in their realm: Creon is punished in Sophocles' *Antigone* by the Olympians for burying Antigone alive, for she is still "theirs," and for failing to bury the dead Polyneices, gobbets of whose flesh are polluting their altars; Hippolytus is abandoned by Artemis, her most ardent worshiper, as his death approaches, for all corpses pollute. Pollution was not a moral concept; and it further complicated relationships between the Greeks and their gods.

Eschatology. In Homer only the gods were by nature immortal, but Elysium was reserved for their favoured sons-in-law, who they exempted from death. Heracles alone gained a place on Olympus by his own efforts. The ordinary hero hated death, for the dead were regarded as strengthless doubles who had to be revived with drafts of blood, mead, wine, and water in order to enable them to speak. They were conducted, it was believed, to the realm of Hades by Hermes; but the way was barred, according to popular accounts, by the marshy river Styx. Across this, Charon ferried all who had received at least token burial, and coins were placed in the mouths of corpses to pay the fare. Originally only great sinners like Ixion, Sisyphus, and Tityus, who had offended the gods personally, were punished in Tartarus. But the doctrines of the Orphics influenced Pindar, Empedocles, and, above all, Plato. According to the latter, the dead were judged in a meadow by Aeacus, Minos, and Rhadamanthus and were consigned either to Tartarus or to the Isles of the Blest. Long periods of purgation were required before the wicked could regain their celestial state, while some were condemned forever. The dead were permitted to choose lots for their next incarnation. Subsequently they drank from the stream of Lethe, the river of oblivion, and forgot all of their previous experiences.

Immortality and death

Sacred writings. Greek religion was not based on a written creed or body of dogma. Nevertheless, certain sacred writings survive in the form of hymns, oracles, inscriptions, and instructions to the dead. Most elaborate are the Homeric Hymns, some of which may have been composed for religious festivals, though their subject matter is almost entirely mythological. Delphic inscriptions include hymns to Apollo but, like the Epidaurian hymn by Isyllus to Asclepius, they are not concerned with liturgy. Delphic oracles are quoted from literary sources but appear, on the whole, to be retrospective concoctions, like the Hebraic–Hellenistic collection of Sibylline prophecies. Questions scratched on folded lead tablets have been found at Dodona, and detailed instructions to the dead, inscribed on gold leaf and possibly of Orphic inspiration, have been found in Greek graves in southern Italy. Papyrus fragments of similar character have been recovered from graves in Macedonia and Thessaly.

Shrines and temples. In the earliest times deities were worshiped in awesome places such as groves, caves, or mountain tops. Mycenaean deities shared the king's palace. Fundamental was the precinct (temenos) allotted to the deity, containing the altar, temple (if any), and other sacral or natural features, such as the sacred olive in the temenos of Pandrosos on the Athenian Acropolis. *Naoi* (temples—literally "dwellings"—that housed the god's image) were already known in Homeric times and, like models discovered at Perachora, were of wood and simple design. Poros and marble replaced wood by the end of the 7th century BC, when temples became large and were constructed with rows of columns on all sides. The image, crude and wooden at first, was placed in the central chamber (cella), which was open at the eastern end. No ritual was associated with the image itself, though it was sometimes paraded. Hero shrines were far less elaborate and had pits for offerings. Miniature shrines also were known.

Oracles and divination

Most oracular shrines included a subterranean chamber, but no trace of such has been found at Delphi, though the Pythia was always said to "descend." At the oracle of Trophonius, discovered in 1967 at Levádhia, incubation was practiced in a hole. The most famous centre of incubation was that of Asclepius at Epidaurus. His temple was furnished with a hall where the sick were advised by the demigod in dreams. Divination was also widely practiced in Greece. Augurs interpreted the flight of birds, while dreams, and even sneezes, were regarded as ominous. Seers also divined from the shape of altar smoke and the conformation of victims' entrails.

Priesthood. Even in the state cults, priesthoods were frequently ancestral prerogatives. Eteobutads organized the cult of the hero-king Erechtheus at Athens; Praxiergids superintended the washing of Athena's robes at the Plynteria; Clytiads and Iamids officiated at the altar of Zeus at Olympia. Although there was no official clergy, since the religious and secular spheres were not sharply divided, professional assistance was available at sacrifices. There was no necessary correspondence between the sex of deities and that of priests. Hera and Athena favoured priestesses, but Isis and Cybele favoured priests. Apollo again inspired the Pythia (priestess) at Delphi but a priest at Ptoon. The mysteries at Eleusis were administered by the Eumolpids and Kerykes. The latter assembled the initiates (*mystae*), while the former provided the Hierophant, who revealed the mysteries in the torchlit Anaktoron (king's shrine) within the great Telesterion, or entrance hall.

Festivals. The precise details of many festivals are obscure. Among the more elaborate was the Panathenaea, which was celebrated at high summer, and every fourth year (the Great Panathenaea) on a more splendid scale. Its purpose, besides offering sacrifice, was to provide the ancient wooden image of Athena, housed in the "Old Temple," with a new robe woven by the wives of Athenian citizens. The Great Panathenaea included a procession, a torch race, athletic contests, mock fights, and bardic recitations. The Great Dionysia was celebrated at Athens in spring. At the end of the ritual the god's image was escorted to the theatre of Dionysus, where it presided over the dramatic contests. It, like its rural counterpart, included phallic features.

Olympic Games

The Olympic Games formed part of the great festival of Zeus held every fourth summer in the god's sacred precinct—the Altis beside the river Alpheius in the western Peloponnese. A truce was proclaimed in order to permit any warring Greeks to compete, and the celebrations lasted five days. Sacrifice and libation were made at the altar of Zeus, where omens were taken and oracles proclaimed, and at the tomb of Pelops and the altar of Hestia. Competitors and judges took the oath to observe the rules, processions were held, bards recited, and winners were honoured at state banquets. The richer and more famous were immortalized by lyric poets, such as Simonides, Bacchylides, and Pindar. Though women were banned, girls competed at the festival of Hera. The games held in honour of Zeus at Nemea, Apollo at Delphi, and Poseidon at the Isthmus followed the Olympian pattern.

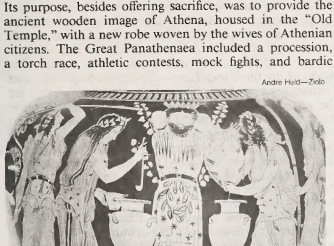
Rites. Sacrifice was offered to the Olympian deities at dawn at the altar in the temenos, which normally stood east of the temple. Representing as it did a gift to the gods, sacrifice constituted the principal proof of piety. The gods were content with the burnt portion of the offering, while the priests and worshipers shared the remainder of the meat. Different animals were sacred to different deities—*e.g.*, heifers to Athena, cows to Hera, pigs to Demeter, bulls to Zeus and Dionysus, dogs to Hecate, game and heifers to Artemis, horses to Poseidon, and asses to Priapus—though the distinctions were not rigorously observed. The practices of ritual washing before sacrifice, sprinkling barley grains, and making token offerings of hair are described by Homer. Victims were required to be free of blemish, or they were likely to offend the deity. Sacrifice also was made to chthonian powers in the evening. Black victims were offered, placed in pits, and the meat was entirely consumed. Sacrifice preceded battles, treaties, or similar events. Human sacrifice appears, if it was practiced at all, to have been the exception. Bloodless sacrifices were made to some deities and heroes.

Prayers and processions

Prayers normally began with compliments to the deity, followed by discreet references to the petitioner's piety, and ended with his special plea. In addressing a prayer to an Olympian, the suppliant stood with his arms raised palm upward. Processions formed part of most gatherings (*panēgyreis*) and festivals. The Panathenaic procession set out from the Pompeion (sacred storehouse) at dawn, headed by maiden basket-bearers (*kanēphoroi*), who carried the sacred panoply. Elders bore boughs (*thallophoroi*) while youths (*ephēboi*) conducted the victims for sacrifice, and cavalry brought up the rear. The robe was spread on the mast of a wheeled ship.

The procession to Eleusis to restore the sacred objects, brought by the *ephēboi* to the Eleusinium some time previously, followed the wooden image of Iacchus (a personification of the ritual cry), which was escorted by its own priest, the *iacchagogos*, and officials. The *mystae* wore myrtle crowns and carried sheaves of grain. Whatever the nature of the mysteries, those initiated returned in a mood of exaltation. Adepts (*epoptai*) were later admitted to more solemn rites (to see an ear of wheat, scoffers said).

Religious art and iconography. Art often portrays incidents relevant to the study of Greek religion, but frequently essential information is missing. On a well-known sarcophagus from Ayías Triádhos in Crete, for example, a priestess dressed in a skin skirt assists at a sacrifice, flanked by wreathed axes on which squat birds. The significance of the scene has been much discussed. The birds have been regarded as epiphanies of deities, giving sacral meaning to the transformations in Homer. Again, since goddesses appear to preponderate in Minoan–Mycenaean art, while male deities are represented on an inferior scale, this has been thought to reflect the general superiority of goddesses in many parts of Greece. In the earliest period, terra-cotta statuettes of deities were small and crude, while the old cult images were made of wood and commonly attributed to Daedalus. When artists turned to bronze and marble,



Painted Greek vase showing a Dionysiac feast, 450–425 BC. In the Louvre, Paris.



Painting showing a dead man (right) receiving an offering of a votive ship and two calves, and the priestess (left) pouring a libation. From a terra-cotta sarcophagus from the necropolis of Ayias Triádhos, Crete, *c.* 1400 BC. In the Archaeological Museum, Crete.
Gad Borel—Boissonnas

they depicted the anthropomorphic deities as idealized human beings. The skill of the Greek sculptor reached an almost unparalleled height in the new temples on the Acropolis of Athens; but while high attainment in the visual arts indicates the presence of a high level of aesthetic consciousness, it would be hazardous to conclude that it necessarily accompanied a profound religious experience. The human form idealized was still used for portraying the gods, but only a brief step was needed to produce an art in which the human form was idealized for its own sake. The growth and decline of religions may be matched by the growth and decline of their art, and works of high artistic quality may inspire, and be inspired by, profound religious emotions; but, as the continued worship of the old wooden aniconic statue of Athena, mentioned above, indicates, it is often the antiquity of a cult object that inspires the awe that surrounds it.

Apart from cult statues and dedications like the Acropolis *korai* ("maidens"), the gods frequently were represented on the pediments, metopes, and friezes of temples, usually in mythological scenes. For the details of ritual, vase painting has proved a fruitful source of information. Dionysiac subjects are common, though usually imaginary, but cult scenes and fertility customs also appear.

If "Greek religion" is understood to denote the beliefs about the Greek gods and their relationships with humanity as recorded in surviving writings from the Homeric poems onward, Greek religion was always evolving. Cultic activity, however, was conservative, as it is in most cultures. Practices continued to be observed that were no longer understood by the worshipers. High claims have been made, and continue to be made, for the quality of Greek religion as a religion, with ethical deities and strong tendencies toward monotheism. Indeed, this is probably the orthodox view. Those who contest it hold that it is incautious to extrapolate from a few scattered passages in a Greek author to produce a systematic theology that can then be used to interpret the rest of the work under discussion. The debate shows no sign of coming to an end; but the heterodox are wont to observe that Xenophanes, Pindar, and Plato evidently read Greek literature in the same way as the heterodox propose that it should be read. Plato's strictures in Books II and III of *The Republic* and elsewhere on Greek religion as he knew it bear eloquent testimony to this.

MYTHOLOGY

Importance of Greek mythology in the Western world

Although people of all countries, eras, and stages of civilization have developed myths that explain the existence and workings of natural phenomena, recount the deeds of gods or heroes, or seek to justify social or political institutions, the myths of the Greeks have remained unrivaled in the Western world as sources of imaginative and appealing ideas. Poets and artists from ancient times to the present have derived inspiration from Greek mythology and have discovered contemporary significance and relevance in classical mythological themes.

Sources of myths: literary and archaeological. *The Homeric poems: the Iliad and the Odyssey.* Herodotus remarked that Homer and Hesiod gave to the Olympian gods their familiar characteristics. Few today would accept this literally. In the first book of the *Iliad,* the son of Zeus and Leto (Apollo, line 9) is as instantly identifiable by his patronymic as are the sons of Atreus (Agamemnon and Menelaus, line 16). In both cases, the audience is expected to have knowledge of the myths that preceded their literary rendering. Most scholars hold that Homer's tone is light and humorous and that the audience is not expected to take the gods seriously. Others reply that little is known to suggest that the Greeks treated Homer, or any other source of Greek myths, as mere entertainment, whereas there are prominent Greeks from Pindar to the later Stoa for whom myths, and those from Homer in particular, are so serious as to warrant bowdlerization or allegorization.

Assumption of prior knowledge

The works of Hesiod: Theogony and Works and Days. The fullest and most important source of myths about the origin of the gods is the *Theogony* of Hesiod. The elaborate genealogies mentioned above are accompanied by folktales and etiological myths. The *Works and Days* shares some of these in the context of a farmer's calendar and an extensive harangue on the subject of justice addressed to Hesiod's possibly fictitious brother Perses. The orthodox view treats the two poems as quite different in theme and treats the *Works and Days* as a theodicy (a natural theology). It is possible, however, to treat the two poems as a diptych, each part dependent on the other. The *Theogony* declares the identities and alliances of the gods, while the *Works and Days* gives advice on the best way to succeed in a dangerous world rendered yet more dangerous by its gods; and Hesiod urges that the most reliable—though by no means certain—way is to be just.

Other literary works. Fragmentary post-Homeric epics, of varying date and authorship, filled the gaps in the accounts of the Trojan War recorded in the *Iliad* and *Odyssey;* the so-called Homeric Hymns (shorter surviving poems) are the source of several important religious myths. Many of the lyric poets preserved various myths, but the odes of Pindar of Thebes (flourished 6th–5th century BC) are particularly rich in myth and legend. The works of the three tragedians—Aeschylus, Sophocles, and Euripides, all of the 5th century BC—are remarkable for the variety of the traditions they preserve. In Hellenistic times (323–30 BC) Callimachus, a 3rd-century-BC poet and scholar in Alexandria, recorded many obscure myths; his contemporary, the mythographer Euhemerus, suggested that the gods were originally human, a view known as Euhemerism. Apollonius of Rhodes, another scholar of the 3rd century BC, preserved the fullest account of the Argonauts in search of the Golden Fleece. In the period of the Roman Empire, the *Library* of the pseudo-Apollodorus (attributed to a 2nd-century-AD scholar), the antiquarian writings of the Greek biographer Plutarch, and the works of Pausanias, a 2nd-century-AD geographer, as well as the *Genealogies* of Hyginus, a 2nd-century-AD mythographer, have provided valuable sources in Latin of later Greek mythology.

Archaeological discoveries. The discovery of the Mycenaean civilization by Heinrich Schliemann, a 19th-century German amateur archaeologist, and the discovery of the Minoan civilization in Crete (from which the Mycenaean ultimately derived) by Sir Arthur Evans, a 20th-century English archaeologist, helped to explain many of the ques-

Significance of Mycenaean and Minoan archaeological discoveries

tions about Homer's epics and provided archaeological proofs of many of the mythological details about gods and heroes. Unfortunately, the evidence about myth and ritual at Mycenaean and Minoan sites is entirely monumental, because the Linear B script (an ancient form of Greek found in both Crete and Greece) was mainly used to record inventories, though the names of gods and heroes have been doubtfully revealed.

Geometric designs on pottery of the 8th century BC depict scenes from the Trojan cycle, as well as the adventures of Heracles. The extreme formality of the style, however, renders much of the identification difficult, and there is no inscriptional evidence accompanying the designs to assist scholars in identification and interpretation. In the succeeding Archaic (*c.* 750–*c.* 500 BC), Classical (*c.* 480–323 BC), and Hellenistic periods, Homeric and various other mythological scenes appear to supplement the existing literary evidence.

Forms of myth in Greek culture. To distinguish among myth, legend, and folktale can be useful, provided it is remembered that the Greeks themselves did not do so.

Religious myths. Greek religious myths are concerned with gods or heroes in their more serious aspects or are connected with ritual. They include cosmogonical tales of the genesis of the gods and the world out of Chaos, the successions of divine rulers, and the internecine struggles that culminated in the supremacy of Zeus, the ruling god of Olympus. They also include the long tale of Zeus's amours with goddesses and mortal women, which usually resulted in the births of younger deities and heroes. The goddess Athena's unique status is implicit in the story of her motherless birth (she was born directly from Zeus); and the myths of Apollo explain that god's sacral associations, describe his remarkable victories over monsters and giants, and stress his jealousy and the dangers inherent in immortal alliances.

Myths of Dionysus, on the other hand, demonstrate the hostility aroused by a novel faith. Some myths are closely associated with rituals, such as the account of the drowning of the infant Zeus's cries by the Curetes, attendants of Zeus, clashing their weapons, or Hera's annual restoration of her virginity by bathing in the spring Canathus. Some myths about heroes and heroines also had a religious basis. The tale of man's creation and moral decline forms part of the myth of the Four Ages (see below). His subsequent destruction by flood and regeneration from stones is partly based on folktale.

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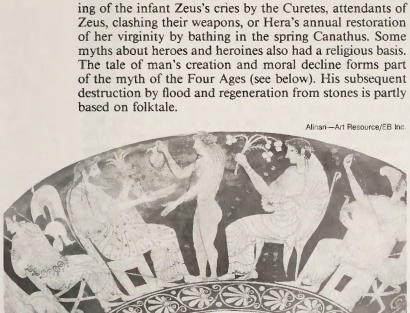

The gods on Olympus: Athena, Zeus, Dionysus, Hera, and Aphrodite; detail of a painting on a Greek cup. In the Museo Municipale, Tarquinia, Italy.

Themes of legends and folktales

Legends. Myths were viewed as embodying divine or timeless truths, whereas legends (or sagas) were quasihistorical. Hence, famous events in epics, such as the Trojan War, were generally regarded as having really happened, and heroes and heroines were believed to have actually lived. Earlier sagas, such as the voyage of the Argonauts, were accepted in a similar fashion. Most Greek legends were embellished with folktales and fiction, but some certainly contain a historical substratum. Such are the tales of more than one sack of Troy, which are supported by archaeological evidence, and the labours of Heracles, which suggest Mycenaean feudalism. Again, the legend of the Minotaur (a being part human, part bull) could have arisen from exaggerated accounts of bull leaping in ancient Crete.

In another class of legends, heinous offenses, such as attempting to make love to a goddess against her will, deceiving the gods grossly by inculpating them in crime, or assuming their prerogatives, were punished by everlasting torture in the underworld. The consequences of social crimes, such as murder or incest, were also described in legend (*e.g.*, the story of Oedipus, who killed his father and married his mother). Legends were also sometimes employed to justify existing political systems or to bolster territorial claims.

Folktales. Folktales, consisting of popular recurring themes and told for amusement, inevitably found their way into Greek myth. Such is the theme of lost persons—whether husband, wife, or child (*e.g.*, Odysseus, Helen of Troy, or Paris of Troy)—found or recovered after long and exciting adventures. Journeys to the land of the dead were made by Orpheus (a hero who went to Hades to restore his dead wife, Eurydice, to the realm of the living), Heracles, Odysseus, and Theseus (the slayer of the Minotaur). The victory of the little man by means of cunning against impossible odds, the exploits of the superman (*e.g.*, Heracles), or the long-delayed victory over enemies are still as popular with modern writers as they were with the Greeks. The successful countering of the machinations of cruel sires and stepmothers (who are often witches), rescues of princesses from monsters, or temporary forgetfulness at a crucial moment are also familiar themes in Greek myth. Recognition by tokens, such as Odysseus' scar or peculiarities of dress, is another common folktale motif. The babes-in-the-wood theme of the exposure of children and their subsequent recovery is also found in Greek myth. The Greeks, however, also knew of the exposure of children as a common practice.

Types of myths in Greek culture. *Myths of origin.* Myths of origin represent an attempt to render the universe comprehensible in human terms. Greek creation myths (cosmogonies) and views of the universe (cosmologies) were more systematic and specific than those of other ancient peoples. Yet their very artistry serves as an impediment to interpretation, since the Greeks embellished the myths with folktale and fiction told for its own sake. Thus, though the aim of Hesiod's *Theogony* is to describe the ascendancy of Zeus (and, incidentally, the rise of the other gods), the inclusion of such familiar themes as the hostility between the generations, the enigma of woman (Pandora), the exploits of the friendly trickster (Prometheus), or struggles against powerful beings or monsters like the Titans (and, in later tradition, the Giants) enhances the interest of an epic account.

According to Hesiod, four primary divine beings first came into existence: the Gap (Chaos), Earth (Gaea), the Abyss (Tartarus), and Love (Eros). The creative process began with the forcible separation of Gaea from her doting consort Heaven (Uranus) in order to allow her progeny to be born. The means of separation employed, the cutting off of Uranus' genitals by his son Cronus, bears a certain resemblance to a similar story recorded in Babylonian epic. The crudity is relieved, however, in characteristic Greek fashion by the friendly collaboration of Uranus and Gaea, after their divorce, in a plan to save Zeus from the same Cronus, his cannibalistic sire.

According to Greek cosmological concepts, the Earth was viewed as a flat disk afloat on the river of Ocean. The Sun (Helios) traversed the heavens like a charioteer and sailed around the Earth in a golden bowl at night. Natural fissures were popularly regarded as entrances to the subterranean house of Hades, home of the dead.

Myths of the ages of the world. From a very early period, Greek myths seem open to criticism and alteration on grounds of morality or of misrepresentation of known facts. In the *Works and Days*, Hesiod makes use of a scheme of Four Ages (or Races): Golden, Silver, Bronze, and Iron. "Race" is the more accurate translation, but "Golden Age" has become so established in English that both terms should be mentioned. These races or ages are separate creations of the gods, the Golden Age belonging to the reign of Cronus, the subsequent races the creation

The Four Ages of Hesiod

of Zeus. Those of the Golden Age never grew old, were free from toil, and passed their time in jollity and feasting. When they died, they became guardian spirits on Earth.

Why the Golden Age came to an end Hesiod failed to explain, but it was succeeded by the Silver Age. After an inordinately prolonged childhood, the men of the Silver Age began to act presumptuously and neglected the gods. Consequently, Zeus hid them in the Earth, where they became spirits among the dead.

Zeus next created the men of the Bronze Age, men of violence who perished by mutual destruction. At this point the poet intercalates the Age (or Race) of Heroes. He thereby destroys the symmetry of the myth, in the interests of history: what is now known as the Minoan–Mycenaean period was generally believed in antiquity to have been a good time to live. (This subjection of myth to history is not universal in Greece, but it is found in writers such as Hesiod, Xenophanes, Pindar, Aeschylus, and Plato.) Of these heroes the more favoured (who were related to the gods) reverted to a kind of restored Golden Age existence under the rule of Cronus (forced into honourable exile by his son Zeus) in the Isles of the Blessed.

The final age, the antithesis of the Golden Age, was the Iron Age, during which the poet himself had the misfortune to live. But even that was not the worst, for he believed that a time would come when infants would be born old, and there would be no recourse left against the universal moral decline. The presence of evil was explained by Pandora's rash action in opening the fatal urn.

Elsewhere in Greek and Roman literature, the belief in successive periods or races is found with the belief that by some means, when the worst is reached, the system gradually (Plato, *Politikos*) or quickly (Virgil, *Fourth Eclogue*) returns to the Golden Age. Hesiod may have known this version; he wishes to have been born either earlier or later. There is also a myth of progress, associated with Prometheus, god of craftsmen; but the progress is limited, for the 19th-century concept of eternal advancement is absent from Greek thought.

Myths of the gods. Myths about the gods described their births, victories over monsters or rivals, love affairs, special powers, or connections with a cultic site or ritual. As these powers tended to be wide, the myths of many gods were correspondingly complex. Thus, the Homeric Hymns to Demeter, a goddess of agriculture, and to the Delian and Pythian Apollo describe how these deities came to be associated with sites at Eleusis, Delos, and Delphi, respectively. Similarly, myths about Athena, the patroness of Athens, tend to emphasize the goddess' love of war and her affection for heroes and the city of Athens; and those concerning Hermes (the messenger of the gods), Aphrodite (goddess of love), or Dionysus describe Hermes' proclivities as a god of thieves, Aphrodite's lovemaking, and Dionysus' association with wine, frenzy, miracles, and even ritual death. Poseidon (god of the sea) was unusually atavistic, in that his union with Earth and his equine adventures appear to hark back to his pre-marine status as a horse or earthquake god. Many myths are treated as trivial and lighthearted; but, as was said above, this judgment rests on the suppressed premise that any divine behaviour that seems inappropriate for a major religion must have seemed absurd and fictitious to the Greeks. It is uncertain whether Homer knew of the judgment of Paris; but he knew the far from trivial consequences for Troy of the favour of Aphrodite and the bitter enmity of Hera and Athena, which the judgment of Paris was composed to explain.

Combinations of myths, legends, and folktales

As time went on, an accretion of minor myths continued to supplement the older and more authentic ones. Thus, the loves of Apollo, virtually ignored by Homer and Hesiod, explained why the bay (or laurel) became Apollo's sacred tree and how he came to father Asclepius, a healing god. Similarly, the presence of the cuckoo on Hera's sceptre at Hermione or the invention of the panpipe were explained by fables. Such etiological myths proliferated during the Hellenistic era, though in the earlier periods genuine examples are harder to detect.

Of folk deities, the nymphs (nature goddesses) personified nature or the life in water or trees and were said to punish unfaithful lovers. Water nymphs (Naiads) were reputed to drown those with whom they fell in love, such as Hylas, a companion of Heracles. Even the gentle Muses (goddesses of the arts and sciences) blinded their human rivals, such as the bard Thamyris. Satyrs (youthful folk deities with bestial features) and Sileni (old and drunken folk deities) were the nymphs' male counterparts. Like sea deities, Sileni possessed secret knowledge that they would reveal only under duress. Charon, the grisly ferryman of the dead, was also a popular figure of folktale.

Myths of heroes. Hero myths included elements from tradition, folktale, and fiction. The saga of the Argonauts, for example, is highly complex and includes elements from folktale and fiction, but the information that the fleet mustered at Colchis may be regarded as genuine legend. Episodes in the Trojan cycle, such as the departure of the Greek fleet from Aulis or Theseus' Cretan expedition and death on Scyros, may belong to traditions dating from the Minoan–Mycenaean world. On the other hand, events described in the *Iliad* probably owe far more to Homer's creative ability than to genuine tradition. Even heroes like Achilles, Hector, or Diomedes are largely fictional, though doubtlessly based on legendary prototypes. The *Odyssey* is the prime example of the wholesale importation of folktales into epic. All the best-known Greek hero myths, such as the labours of Heracles and the adventures of Perseus, Cadmus, Pelops, or Oedipus, depend more for their interest on folktales than legend. Certain heroes—Heracles, the Dioscuri (the twins Castor and Pollux), Amphiaraus (one of the Argonauts), or Hyacinthus (a youth loved by Apollo and accidentally killed)—may be regarded as partly legend and partly religious myth. Thus, whereas Heracles, a man of Tiryns, may originally have been a historical character, the myth of his demise on Oeta and subsequent elevation to full divinity is closely linked with a cult. In time, Heracles' popularity was responsible for connecting his story with the Argonauts, an earlier attack on Troy, and with Theban myth. Similarly, the exploits of the Dioscuri are those of typical heroes: fighting, carrying off women, and cattle rustling. After their death they passed six months alternately beneath the Earth and in the world above, which suggests that their worship, like that of Persephone (the daughter of Zeus and Demeter), was connected with fertility or seasonal change.

Myths of seasonal renewal. Certain myths, in which goddesses or heroes were temporarily incarcerated in the underworld, were allegories of seasonal renewal. Perhaps the best-known myth of this type is the one telling how Hades (Latin Pluto), the god of the underworld, carried Persephone off to be his consort, causing her mother Demeter, the goddess of grain, to allow the earth to grow barren out of grief. Because of her mother's grief, Zeus permitted Persephone to spend four months of the year in the house of Hades and eight in the light of day. In less benign climates, she was said to spend six months of the year in each. Some scholars hold that Persephone's time below ground represents the summer months, when Greek fields are parched and bare; but the *Hymn to Demeter*, the earliest source, states explicitly that Persephone returns when the spring flowers are flourishing (line 401). Myths of seasonal renewal, in which the deity dies and returns to life at particular times of the year, are plentiful. An important Greek example is the Cretan Zeus, mentioned above.

Myths involving theriolatry. Many Greek myths involve animal transformations, though there is no proof that theriolatry (animal worship) was ever practiced by the Greeks. Gods sometimes assumed the form of beasts in order to deceive goddesses or women. Zeus, for example, assumed the form of a bull when he carried off Europa, a Phoenician princess, and appeared in the guise of a swan in order to attract Leda, wife of a king of Sparta. Poseidon took the shape of a stallion to beget the wonder horses Arion and Pegasus.

Deities appearing in nonhuman form

These myths do not suggest theriolatry. No worship is offered to the deity concerned. The animals serve other purposes in the narratives. Bulls were the most powerful animals known to the Greeks and may have been worshiped in the remote past. But for the Greeks in even the earliest sources, there is no indication that Zeus or



Heracles fighting with the Amazons, detail from a volute crater attributed to Euphronius, *c.* 500 BC. In the Museo Archeologico, Arezzo, Italy.
Alinari—Art Resource/EB inc.

Poseidon were once bulls or horses, or that Hera was ever "ox-eyed" other than metaphorically, or that "gray-eyed" Athena was ever "owl-faced."

Deities appearing in human form

Other types. Other types of myth exemplified the belief that the gods sometimes appeared on Earth disguised as men and women and rewarded any help or hospitality offered them. Baucis, an old Phrygian woman, and Philemon, her husband, for example, were saved from the flood by offering hospitality to Zeus and Hermes, both of whom were in human form. The punishment of men's presumption in claiming to be the gods' superiors, whether in musical skill or even the number of their children, is described in several myths. The gods' jealousy of their musical talents appears in the beating and flaying of the flute-playing Satyr, Marsyas, by Athena and Apollo, as well as in the attaching of ass's ears to King Midas for failing to appreciate the superiority of Apollo's music to that of the god Pan. Jealousy was the motive for the slaying of Niobe's many children, because of Niobe's flaunting her fecundity to the goddess Leto, who had only two offspring. Similar to such stories are the moral tales about the fate of Icarus, who flew too high on homemade wings, or the myth about Phaethon, the son of Helios, who failed to perform a task too great for him (controlling the horses of the Sun).

Transformation into flowers or trees, whether to escape a god's embraces (such as Daphne, a nymph transformed into a laurel tree), as the result of an accident (such as Hyacinthus, a friend of Apollo, who was changed into a flower), or because of pride (*e.g.,* the beautiful youth Narcissus who fell in love with his own reflection and was changed into a flower), were familiar themes in Greek myth.

Also popular were myths of fairylands, such as the Garden of the Hesperides (in the far west) or the land of the Hyperboreans (in the far north), or encounters with monstrous or outlandish people, such as the Centaurs or Amazons.

Greek mythological characters and motifs in art and literature. People of all eras have been moved and baffled by the deceptive simplicity of Greek myths, and Greek mythology has had a profound effect on the development of Western civilization.

The earliest visual representations of mythological characters and motifs occur in late Mycenaean and sub-Mycenaean art. Though identification is controversial, Centaurs, a Siren, and even Zeus's lover Europa have been recognized. Mythological and epic themes are also found in Geometric art of the 8th century BC, but not until the 7th century did such themes become popular in both ceramic and sculptured works. During the Classical and subsequent periods, they became commonplace. The birth of Athena was the subject of the east pediment of the Parthenon in Athens, and the legend of Pelops and the labours of Heracles was the subject of the corresponding pediment and the metopes (a space on a Doric frieze) of the Temple of Zeus at Olympia. The battles of gods with Giants and of Lapiths (a wild race in northern Greece) with Centaurs were also favourite motifs. Pompeian frescoes reveal realistic representations of Theseus and Ariadne, Perseus, the fall of Icarus, and the death of Pyramus.

Resurgence of Greek mythological motifs

The great Renaissance masters added a new dimension to Greek mythology. Among the best-known subjects of Italian artists are Botticelli's "Birth of Venus," the Ledas of Leonardo da Vinci and Michelangelo, and Raphael's "Galatea."

Through the medium of Latin and, above all, the works of Ovid, Greek myth influenced medieval poets such as Petrarch and Boccaccio in Italy and Chaucer in England; Dante in Italy during the Renaissance; and, later, the English Elizabethans and John Milton. Racine in France and Goethe in Germany revived Greek drama, and nearly all the major English poets from Shakespeare to Robert Bridges turned for inspiration to Greek mythology. In more recent times, classical themes have been reinterpreted by such major dramatists as Jean Anouilh, Jean Cocteau, and Jean Giraudoux in France, Eugene O'Neill in America, and T.S. Eliot in England and by great novelists such as James Joyce (Irish) and André Gide (French). The German composers Christoph Gluck (18th century) and Richard Strauss (20th century), the German-French composer Jacques Offenbach (19th century), and many others have set Greek mythological themes to music.

(J.R.T.P./A.W.H.A.)

Roman religion

This section deals with the beliefs and practices of the inhabitants of the Italian peninsula from ancient times until the ascendancy of Christianity in the 4th century AD.

NATURE AND SIGNIFICANCE

Object of Roman religion

The Romans, according to the orator and politician Cicero, excelled all other peoples in the unique wisdom that made them realize that everything is subordinate to the rule and direction of the gods. Yet Roman religion was based not on divine grace but instead on mutual trust (*fides*) between god and man. The object of Roman religion was to secure the cooperation, benevolence, and "peace" of the gods (*pax deorum*). The Romans believed that this divine help would make it possible for them to master the unknown forces around them that inspired awe and anxiety (*religio*), and thus they would be able to live successfully. Consequently, there arose a body of rules,

the *jus divinum* ("divine law"), ordaining what had to be done or avoided.

These precepts for many centuries contained scarcely any moral element; they consisted of directions for the correct performance of ritual. Roman religion laid almost exclusive emphasis on cult acts, endowing them with all the sanctity of patriotic tradition. Roman ceremonial was so obsessively meticulous and conservative that, if the various partisan accretions that grew upon it throughout the years can be eliminated, remnants of very early thought can be detected near the surface.

This demonstrates one of the many differences between Roman religion and Greek religion, in which such remnants tend to be deeply concealed. The Greeks, when they first began to document themselves, had already gone quite a long way toward sophisticated, abstract, and sometimes daring conceptions of divinity and its relation to man. But the orderly, legalistic, and relatively inarticulate Romans never quite gave up their old practices. Moreover, until the vivid pictorial imagination of the Greeks began to influence them, they lacked the Greek taste for seeing their deities in personalized human form and endowing them with mythology. In a sense, there is no Roman mythology, or scarcely any. Although discoveries in the 20th century, notably in the ancient region of Etruria (between the Tiber and Arno rivers, west and south of the Apennines), confirm that Italians were not entirely unmythological, their mythology is sparse. What is found at Rome is chiefly only a pseudomythology (which, in due course, clothed their own nationalistic or family legends in mythical dress borrowed from the Greeks). Nor did Roman religion have a creed; provided that a Roman performed the right religious actions, he was free to think what he liked about the gods. And, having no creed, he usually deprecated emotion as out of place in acts of worship.

In spite, however, of the antique features not far from the surface, it is difficult to reconstruct the history and evolution of Roman religion. The principal literary sources, antiquarians such as the 1st-century-BC Roman scholars Varro and Verrius Flaccus, and the poets who were their contemporaries (under the late Republic and Augustus), wrote 700 and 800 years after the beginnings of Rome. They wrote at a time when the introduction of Greek methods and myths had made erroneous (and flattering) interpretations of the distant Roman past unavoidable. In order to supplement such conjectures or facts as they may provide, scholars rely on surviving copies of the religious calendar and on other inscriptions. There is also a rich, though frequently cryptic, treasure-house of material in coins and medallions and in works of art.

HISTORY

Early Roman religion. For the earliest times, there are the various finds and findings of archaeology. But they are not sufficient to enable scholars to reconstruct archaic Roman religion. They do, however, suggest that early in the 1st millennium BC, though not necessarily at the time of the traditional date for the founding of Rome (753 BC), Latin and Sabine shepherds and farmers with light plows came from the Alban Hills and the Sabine Hills, and that they proceeded to establish villages at Rome, the Latins on the Palatine Hill and the Sabines (though this is uncertain) on the Quirinal and Esquiline hills. About 620 the communities merged, and *c.* 575 the Forum Romanum between them became the town's meeting place and market.

Deification of functions. From such evidence it appears that the early Romans, like many other Italians, sometimes saw divine force, or divinity, operating in pure function and act, such as in human activities like opening doors or giving birth to children, and in nonhuman phenomena such as the movements of the sun and seasons of the soil. They directed this feeling of veneration both toward happenings that affected human beings regularly and, sometimes, toward single, unique manifestations, such as a mysterious voice that once spoke and saved them in a crisis (Aius Locutius). They multiplied functional deities of this kind to an extraordinary degree of "religious atomism," in which countless powers or forces were identified with one phase of life or another. Their functions were sharply defined; and in approaching them it was important to use their right names and titles. If one knew the name, one could secure a hearing. Failing that, it was often best to cover every contingency by admitting that the divinity was "unknown" or adding the precautionary phrase "or whatever name you want to be called" or "if it be a god or goddess."

Veneration of objects. The same sort of anxious awe was extended not only to functions and acts but also to certain objects that inspired a similar belief that they were in some way more than natural. This feeling was aroused, for example, by springs and woods, objects of gratitude in the torrid summer, or by stones that were often believed to be meteorites—*i.e.,* had apparently reached the earth in an uncanny fashion. To these were added products of human action, such as burial places and boundary stones, and inexplicable things, such as Neolithic implements (probably the mysterious meteorites were often these) or bronze shields (artifacts that had strayed in from more advanced cultures).

To describe the powers in these objects and functions that inspired the *horror,* or sacred thrill, the Romans eventually employed the word *numen,* suggestive of a god's nod, *nutus;* though so far there is no evidence that this usage was earlier than the 2nd century BC. The application of the word spirit to *numen* is anachronistic in regard to early epochs because it presupposes a society capable of greater abstraction. Nor must the term mana, used by Melanesians to describe their own concept of superhuman forces, be introduced too readily. The two societies are not necessarily analogous and, besides, the deduction from such comparisons that the Romans experienced an impersonal, pre-deistic, primordial stage of religion that neatly preceded the personal stage cannot be regarded as correct. On the contrary, from the very earliest times, the supernatural forces that they envisaged included a number of deities in analogous human forms; among them were certain "high gods." Foremost among these was a divinity of the sky, Jupiter, akin to the sky gods of other early Indo-European-speaking peoples, the Sanskrit Dyaus and Greek Zeus. Not yet, probably, a Supreme Being, though superior in some sense to other divine powers, this god of the heavens was easily linked with the forces of function and object, with lightning and weather, or with the uncanny stone that came from on high and was called Jupiter Lapis. High gods

Purpose of sacrifice and magic. These gods and sacred functions and objects seemed charged with power because they were mysterious and alarming. In order to secure their food supply, physical protection, and growth in numbers, the early Romans believed that such forces had to be propitiated and made allies. Sacrifice was necessary. The product sacrificed would revitalize the divinity, which was seen as a power of action and therefore likely to run down unless so revitalized. By this nourishment he or it would become able and ready to fulfill requests. And so the sacrifice was accompanied by the phrase *macte esto!* ("be you increased!").

Prayer was a normal accompaniment of sacrifice, and as a conception of the divine powers gradually developed, it contained varying ingredients of flattery, cajolery, and attempted justification; but it also was compounded by magic—the attempt not to persuade nature, but to coerce it. Though the authorities (*e.g., c.* 451–450 BC, Law of the Twelve Tables) sought to limit its noxious aspects, magic continued to abound throughout the ancient world. Even official rites remained full of its survivals, notably the annual festival of the Lupercalia and the ritual dances of the Salii in honour of Mars. Romans in historical times regarded magic as an oriental intrusion, but Italian tribes, such as the Marsi and Paeligni, were famous for such practices. Among them curses figured prominently, and curse inscriptions from *c.* 500 BC onward have been found in large numbers. There were also numerous survivals of taboo, a negative branch of magic: people were admonished to have no dealings with strangers, corpses, newborn children, spots struck by lightning, etc., lest harm would befall them.

Religion in the Etruscan period. The apparent amalgamation of the Latin and Sabine villages of Rome coincided with, or more probably was soon followed by, a period in which Rome was under the control of at least one dynasty (the Tarquins) from Etruria, north of the Tiber (*c.* 575–510 BC, though some scholars would extend this domination to *c.* 450).

Importance of ritual. The Etruscans felt profound religious anxieties and were more devoted to ritual than any other people of the ancient Western world. Though sources are, again, late and unsatisfactory, it appears that they possessed a comprehensive collection of rules regulating these rites. Etruscan culture was heavily based on influences from Greece in its orientalizing period, conveyed mainly through Greek centres (such as Cumae) in Campania, colonized by Euboeans, who were also prominent in Syrian markets. But the religion of Etruria proclaims a very un-Greek view of the abasement and nonentity of man before the gods and their will.

Divination and views of the afterlife

To the Etruscans the whole fanatical effort of life was directed toward forcing their deities, led by Tinia or Tin (Jupiter), to yield up their secrets by divination. They saw an intimate link existing between heaven and earth, which seemed to echo one another within a unitary system, and they were more ambitious than either Greeks or Romans in their claims to foretell the future. They also formed an exceptionally complex, rich, and imaginative picture of the afterlife. The living were perpetually obsessed by their care for the dead, expressed in elaborate, magnificently equipped and decorated tombs and lavish sacrifices. For, in spite of beliefs in an underworld, or Hades, there was also a conviction that the individuality of the dead somehow continued in their mortal remains; and it was therefore imperative that they take pleasure in their graves or tombs and not return to haunt the living. From the 4th century BC onward, after the Etruscans had lost their political power to Rome, their art depicts horrors indicating an increasing fear of what death might bring.

Influence on Roman religion. The Roman religion continued to display certain obvious debts to the period when the city had been under Etruscan control. It is true that the Roman shades (Di Manes) were much less substantial than the fantastic Etruscan conceptions and, although Etruscan divination by the liver and entrails survived and later became increasingly fashionable in Rome, Roman diviners in general, products of a more realistic and prosaic society, never aspired to such precise information about the future as the Etruscans had hoped to gain. Yet, it was the Etruscans who first gave a vigorous definition to Italian religious forms. Indeed, many of the religious features that patriotic historians preferred to ascribe to the mythical King Numa Pompilius (who was supposed to have been Romulus' Sabine successor in the 8th century BC—the man of peace following the man of war) date, in fact, from the period of Etruscan domination two centuries later. Nevertheless, Romans acknowledged a debt to Etruria that included much ceremony and ritual and the plan, appearance, and decoration of a number of temples, notably the great shrine of the Capitoline Triad, Jupiter, Juno, and Minerva. The Romans also were indebted to the Etruscans for their first statues of gods, including the cult image of Jupiter commissioned from an Etruscan for the Capitoline temple. Such statuary, showing the gods in human shape, encouraged the Romans to think of their gods in this way, with the consequent possibility of investing them with myths, which thereafter gradually accumulated around them in the form of Hellenic stories often infused with a native patriotic element.

The calendar

Above all, Rome owed to its Etruscan kings its religious calendar. In addition to poetical works discussing the calendar in antiquarian fashion, such as the *Fasti* of Ovid, there are extant fragments of about 40 copies of the calendar itself, in a revised shape established by Julius Caesar. Besides the Julian revision, there is an incomplete pre-Caesarian, Republican calendar, the Fasti Antiates, discovered at Antium (Anzio); it dates from after 100 BC. It is possible to detect in these calendars much that is very ancient, including a pre-Etruscan 10-month solar year. However, the basis of the calendars, in their surviving form, is later, since it consists of an attempt to reconcile the solar and lunar year, in accordance with Babylonian calculations. This endeavour belongs to the period of Etruscan domination of Rome—for example, the names of the months April and June (in their Roman form) come from Etruria. Moreover, the presence or absence of certain festivals permits a dating approximating to the time of Etruscan domination in the later 6th century BC. Additional modifications were introduced in the following century and again when the calendar was subsequently published (30 BC).

The festivals it records, of which the earliest are indicated in large letters, reflect a period of transition between country and town life. Though local cult continued to remain active, many forms of worship hitherto maintained by families and farms had now been taken over by the comparatively mature Roman state. The state management blocked any tendency toward spiritualization and removed the need for any vigorous individual participation; however, by ensuring that the gods were conciliated by a schedule corresponding to the regular process of nature, it made the individual citizens feel for centuries that relations with the supernatural were being maintained safely.

Religion in the early Republic. Even if, as tradition records, a coup d'état dislodged the Etruscan kings before 500 BC, in the first half of the 5th century there was no weakening of trade relations with Etruria. Its southern cities, such as Caere (Cerveteri) and Veii close to Rome, had long used the Greek city of Cumae as a commercial outlet, converting it into an important grain supplier. And now Rome, faced with a shortage of grain, arranged for it to be imported from Cumae. The same city also influenced the foundation of Roman temples in the Greek style. Rome, which had already become accustomed to Greek religious customs in the Etruscan epoch, now showed a willingness to absorb them. This forms a strange contrast to its deeply ingrained religious conservatism. Moreover, at some quite early stage (though there is no positive evidence of the practice until the 3rd century), Romans borrowed from elsewhere in Italy a special ritual (*evocatio*) for inviting the patron deities of captured towns to abandon their homes and migrate to Rome.

Influence of Greek religion

In an emergency in 399 BC, during a difficult siege of Veii, Rome carried Hellenization further by importing a Greek rite in which, as an appeal to emotional feeling, images of pairs of gods were exhibited on couches before tables spread with food and drink; this rite (*lectisternium*) was designed to make them Rome's welcome guests. From the same century onward, if not earlier, pestilences were averted by another ritual (*supplicatio*), in which the whole populace went around the temples and prostrated themselves in Greek fashion. Later the custom was extended to the celebration of victories.

Religion in the later Republic: crises and new trends. The *lectisternium* was repeated, with increased elaboration and pomp, in 217 BC during a period in which emotional religion was running rampant because of Hannibal's invasion of Italy in the Second Punic War. Faced with a flood of fears and anxieties and reports of many alarming and extraordinary events, Rome took precautions to secure the favour of all manner of gods. Among them, as a desperate attempt at novelty when appeals to the usual deities seemed stale, was the introduction of the Great Mother of Asia Minor, Cybele (204 BC). Eighteen years later, the equally orgiastic worship of Dionysus (Bacchus) was coming in so rapidly and violently, by way of southern Italy, that the Senate, scenting subversion, repressed its practitioners. But these and other mystery religions, promising initiation, afterlife, and an excitement that Roman national cults could not provide, had come to stay and, although there were long periods of official disapproval before acclimatization was completed, they gradually played an immense part upon the religious scene. Eastern astrology, too, became extremely popular. It was based on the conviction that, since there is cosmic sympathy between the earth and other heavenly bodies, and since, therefore, the emanations of these bodies influence the earth, men must learn how to foresee their dictates—and outwit them.

Influence of Stoicism

Astrological practices received encouragement from Stoic philosophy, which was introduced to Rome in the 2nd and early 1st centuries BC, notably by Panaetius and Posidonius. The Stoics saw this pseudoscience as proof of the Platonic unity of the universe. Stoicism affected Roman religious thinking in at least three other ways. First, it had a deterministic effect, encouraging a widespread belief in Fate and also, somewhat illogically, in Fortune, both of which were revered in other parts of the Mediterranean and Middle Eastern world. Second, Stoicism infused a new spirituality into religious thinking by its insistence that the human soul is part of the universal spirit and shares its divinity. Third, the moral implication of this, as the Stoics pointed out, was that all men are brothers and must treat each other accordingly. This demonstration struck a chord in the psychology of the Romans, who possessed strongly ethical inclinations and now, at last, saw this trend supported and justified by a philosophical sanction that their formalistic religion had not provided. In changing times of imperialism, materialism, and widespread heart-searching, the state religion had failed to fill the vacuum, and philosophy stepped in instead. At the same time the negative approach of Roman religion to the afterlife was counteracted by an influx of speculations that blended theology, mysticism, and magic and claimed the mythical Orpheus and the part historical, part legendary Pythagoras as prophets.

While their national poet Ennius helped to diffuse such beliefs, he and the comic dramatist Plautus ridiculed the traditional Roman gods on the stage. The upper-class attitude of the times was expressed by the historian Polybius, the priestly lawyer Scaevola, the scholarly Varro, and the orator and philosopher Cicero, who maintained that the importance of religion was political, residing in its power to keep the multitude under control, to prevent social chaos, and to promote patriotic feeling.

The imperial epoch: the final forms of Roman paganism. After the prolonged horrors of civil war had ended (30 BC), the victorious Octavian, the adoptive son of the dictator Caesar and founder of the imperial regime or principate, decided, correctly, that the ancient religion was far from dead and that the restoration of all its forms would respond to a strong popular, instinctive belief that the disasters of the past generations had been due to the neglect of religious duties.

Deification of Caesar and Augustus

The imperial cult. Octavian himself took the name Augustus, a term indicating a claim to reverence. This did not make him a god in his lifetime, but, combined with the insertion of his *numen* and his *genius* (originally the procreative power that enables a family to be carried on) into certain cults, it prepared the way for his posthumous deification, just as Caesar had been deified before him. Both were deified by the state because they seemed to have given Rome gifts worthy of a god. From earliest times in Greece there had been an idea that, if someone saved you, you should pay him the honours you would offer to a god. Alexander the Great and his successors had demanded reverence as divine saviours, and Ptolemy II Philadelphus of Egypt introduced a cult of his own living person. The Stoic belief that the human soul was part of the world soul was a corollary of the view that great men possessed a larger share of this divine element. Moreover, the 3rd-century-BC mythographer Euhemerus had elaborated a theory that the gods themselves had once been human; this idea was readily adapted to the supposed careers of Heracles (Hercules) and the Dioscuri (Castor and Polydeuces [Pollux]); and the Romans applied it to their own gods Saturn and Quirinus, the latter identified with the national founder, Romulus, risen to heaven. And so it became customary—if emperors (and empresses) were approved of in their lives—to raise them to divinity after their deaths. They were called *divi*, not *dei* like the Olympian gods; the latter were prayed to, but the former were regarded with veneration and gratitude.

As the empire proceeded and the old religion seemed more and more irrelevant to people's personal preoccupations and successive national emergencies, the cult of the *divi*, subsequently grouped together in a single Hall of Fame, remained foremost among the patriotic cults that were increasingly encouraged as unifying forces. Concentrating on the protectors of the emperor and the nation, they included the worship of Rome herself, and of the *genius* of the Roman people; for the army a number of special military celebrations are recorded on the Calendar of Doura-Europus in Mesopotamia (Feriale Duranum, *c.* AD 225–27). As for the ruling emperors, they were more and more frequently treated as divine, with varying degrees of formality, and officially they often were compared with gods. As monotheistic tendencies grew, however, this custom led not so much to their identification with the gods as to the doctrine that they were the elect of the divine powers, who were defined as their companions (*comites*). In pursuance of this way of thinking, as official paganism approached its last days, the emperors Diocletian and Maximian took the names Jovius and Herculius, respectively, after their Companions and Patrons Jupiter and Hercules.

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Apotheosis of Faustina, wife of Marcus Aurelius, ancient bas-relief. In the Capitoline Museum, Rome.

Speculative religious thought

Introduction of Christianity and Mithraism. By now, however, the humanistic idea that men could become gods had ceased to have any plausibility. Plotinus and his Neoplatonism, the dominant philosophy of the pagan world from the mid-3rd century AD, had given powerful, mystical shape to the Platonic and Stoic conception that the universe is governed by a single force. On the other hand, the greatest religious figure of the century, the Iranian Mani, who had started to preach in Mesopotamia *c.* 240, dramatically preached the opposing dualistic idea that the world is the creation not only of a good power but of an evil one as well. Mani's church, which alarmed Diocletian and for a time attracted the great Christian theologian St. Augustine, absorbed many of the innumerable cults of Gnostics who claimed special knowledge (*gnōsis*) by illumination and revelation and taught how people can purge the nonspiritual from within themselves and escape their earthly prison. More impressively, the cult of the Persian Mithra blended the dualism of Mani with the emotional initiations of the mystery religions (corrected by a much sterner tone of moral endeavour) and became a strong link between the cult of the Sun (which appealed to contemporary monotheists) and the fashionable revulsion from the senses that was shortly to lead to Christian monasticism. Like Christianity, Mithraism had its sacraments; but the life of Mithra exercised a less far-reaching appeal than the life of Christ, and Mithra's cult excluded women.

Christianity, unique in its universal charity and unique

also in its demand for a noble effort of faith in Jesus' blend of divinity and humanity, was the religion that prevailed in the Roman world. It satisfied the emperor Constantine's impulsive need for divine support, and from AD 312 onward, by a complex and gradual process, it became the official religion of the empire.

The survival of Roman religion. For a time, coins and other monuments continued to link Christian doctrines with the worship of the Sun, to which Constantine had been addicted previously. But even when this phase came to an end, Roman paganism continued to exert other, permanent influences, great and small. The emperors passed on to the popes the title of chief priest, *pontifex maximus*. The saints, with their distribution of functions, often seemed to perpetuate the many *numina* of ancient tradition. The ecclesiastical calendar retains numerous remnants of pre-Christian festivals—notably Christmas, which blends elements including both the feast of the Saturnalia and the birthday of Mithra. But, most of all, the mainstream of Western Christianity owed ancient Rome the firm discipline that gave it stability and shape, combining insistence on established forms with the possibility of recognizing that novelties need not be excluded, since they were implicit from the start.

BELIEFS, PRACTICES, AND INSTITUTIONS

The earliest divinities. The early Romans, like other Italians, worshiped not only purely functional and local forces but also certain high gods. Chief among them was the sky god Jupiter, whose cult, at first limited to the communities around the Alban Hills, later gained Rome as an adherent. The Romans gave Jupiter his own priest (*flamen*), and the fact that there were two other senior *flamines,* devoted to Mars and Quirinus, confirms other indications that the cults of these three deities, envisaged perhaps in some sort of association, belonged to a very early stratum (though the theory of their correspondence to the three-class social division of the early Indo-European-speaking peoples is generally unacceptable). Mars, whose name may or may not be Indo-European, was a high god of many Italian peoples, as liturgical bronze tablets found at Iguvium (Gubbio), the Tabulae Iguvinae (*c.* 200–*c.* 80 BC), confirm, protecting them in war and defending their agriculture and animals against disease. Later, he was identified with the Greek god of war, Ares, and also was regarded as the father of Romulus. Mars Gradivus presided over the beginning of a war and Mars Quirinus over its end, but earlier Quirinus had apparently, as a separate deity, been the patron of the Quirinal village before its amalgamation with the Palatine; subsequently he was believed to have been the god that Romulus became when he ascended into heaven.

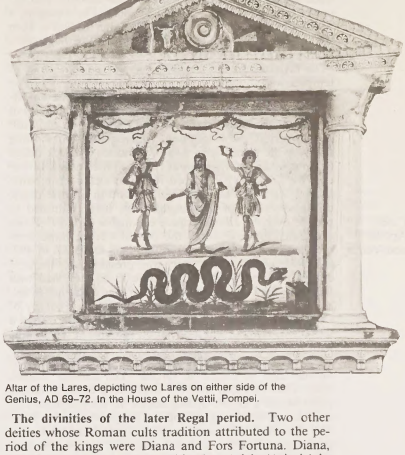
Jupiter, Mars, and Quirinus

Two other forces that belong to an early phase were Janus and Vesta, the powers of the door and hearth, respectively. Janus, who had no Greek equivalent, was worshiped beside the Forum in a small shrine with double doors at either end and originated either from a divine power that regulated the passage over running water or rather, perhaps, from sacred doorways like those found on the art of Bronze Age Mycenae. Janus originally stood for the magic of the door of a private house or hut and later became a part of the state religion. The gates of his temple were formally closed when the state was at peace, a custom going back to the primitive war magic that required armies to march out to battle by this properly sanctified route. Vesta, too, passed from the home to the state, always retaining a circular temple reminiscent of the primitive huts whose form can be reconstructed from traces left in the earth and from surviving funerary urns. Vesta's shrine contained the eternal fire, but the absence of a statue indicates that it preceded the anthropomorphic period; its correspondence with the Indian *garhapatya,* "house-father's fire," suggest an origin prior to the time of the differentiation of the Indo-European-speaking peoples. The cultic site just outside the area of the primitive Palatine settlement indicates that there had been a form of fire worship even earlier than Vesta's (dedicated to the deity Caca) on the Palatine itself. The cult of Vesta, tended by her Virgins, continued to flourish until the end of antiquity, endowed with an important role in the sacred protectorship of Rome.

Janus and Vesta

The Di Manes, collective powers (later "spirits") of the dead, may mean "the good people," an anxious euphemism like the Greek name of "the kindly ones" for the Furies. As a member of the family or clan, however, the dead man or woman would, more specifically, be one of the Di Parentes; reverence for ancestors was the core of Roman religious and social life. Di Indigetes was a name given collectively to these forebears, as well as to other deified powers or spirits who likewise controlled the destiny of Rome. For example, the name Indiges is applied to Aeneas, whose mythical immigration from Troy led to the eventual foundation of the city. According to an inscription of the 4th century BC (found at Tor Tignosa, 15 miles south of Rome), Aeneas is also called Lar, which indicates that the Lares, too, were originally regarded as divine ancestors and not as deities who presided over the farmland. The Lares were worshiped wherever properties adjoined, and inside every home their statuettes were placed in the domestic shrine (*lararium*). Under state control they moved from boundaries of properties to crossroads (where Augustus eventually associated his own *genius* with the cult) and were worshiped as the guardian spirits of the whole community (Lares Praestites). The cult of the Di Penates likewise moved from house to state. From very early times the Penates, the powers that ensured that there was enough to eat, were worshiped in every home. They also came to be regarded as national protectors, the Penates Publici. Originally they were synonymous with the Dioscuri. The legend that they had been brought to Italy by Aeneas with his followers from Troy was imported from Lavinium (Pratica di Mare) when the early Romans incorporated that town into their own state.

Manes, Indigetes, Lares, and Penates



Brogi—Alinari from Art Resource/EB Inc.

Altar of the Lares, depicting two Lares on either side of the Genius, AD 69–72. In the House of the Vettii, Pompei.

The divinities of the later Regal period. Two other deities whose Roman cults tradition attributed to the period of the kings were Diana and Fors Fortuna. Diana, an Italian wood goddess worshiped at Aricia (Ariccia) in Latium and prayed to by women who wanted children, was in due course identified with the Greek Artemis. Her temple on the Aventine Hill (*c.* 540 BC) with its statue, an imitation of a Greek model from Massilia (Marseille), was based on the Temple of Artemis of Ephesus. By establishing such a sanctuary, the Roman monarch Servius Tullius hoped to emulate the Pan-Ionian League among the Latin peoples. Fors Fortuna, whose temple across the

Tiber from the city was one of the few that slaves could attend, was similar to the oracular shrines of Fortuna at Antium (Anzio) and Praeneste (Palestrina). Originally a farming deity, she eventually represented luck. She came to be identified with Tyche, the patroness of cities and goddess of Fortune among the Hellenistic Greeks.

In Roman tradition, Servius Tullius reigned between two Etruscan kings, Tarquinius Priscus and Tarquinius Superbus. The Etruscan kings began and perhaps finished the most important Roman temple, devoted to the cult of the Capitoline Triad, Jupiter, Juno, and Minerva (the dedication was believed to have taken place in 509 or 507 BC after the expulsion of the Etruscans). Such triads, housed in temples with three chambers (*cellae*), were an Etruscan institution. But the grouping of these three Roman deities seems to be owed to Greek anthropomorphic ideas, since Hera and Athena, with whom Juno and Minerva were identified, were respectively the wife and daughter of Zeus (Jupiter). In Italy, Juno (Uni in Etruscan) was sometimes the warlike high goddess of a town (*e.g.,* Lanuvium [Lanuvio] in Latium), but her chief function was to supervise the life of women, and particularly their sexual life. The functions of Minerva concerned craftsmen and reflected the growing industrial life of Rome. Two gods with Etruscan names, both worshiped at open altars before they had temples in Rome, were Vulcan and Saturn, the former a fire god identified with the Greek blacksmiths' deity Hephaestus, and the latter an agricultural god identified with Cronus, the father of Zeus. Saturn was worshiped in Greek fashion, with head uncovered.

Capitoline Triad

The focal point of the cult of Hercules was the Great Altar (Ara Maxima) in the cattle market, just inside the boundaries of the primitive Palatine settlement. The altar may be traced to a shrine of Melkart established by traders from Phoenicia in the 7th century BC. The name of the god, however, was derived from the Greek Heracles, whose worship spread northward from southern Italy, brought by traders who venerated his journeys, his labours, and his power to avert evil. In a market frequented by strangers, a widely recognized divinity of this type was needed to keep the peace. The Greek cult, at first private, perhaps dates from the 5th century BC.

The divinities of the Republic. An important series of temples was founded early in the 5th century BC. The completion of the temple of the Etruscan Saturn was attributed to this time (497). A shrine honouring the twin horsemen, the Dioscuri (Castor and Pollux), was also built in this period. An inscription from Lavinium describing them by the Greek term *kourot* indicates a Greek origin (from southern Italy) without Etruscan mediation. In legend, the Dioscuri had helped Rome to victory in a battle against the Latins at Lake Regillus, and in historic times, on anniversaries of that engagement, they continued to preside over the annual parade of knights (*equites*). From southern Italy, too, came the cult of Ceres, whose temple traditionally was vowed in 496 and dedicated in 493. Ceres was an old Italian deity who presided over the generative powers of nature and came to be identified with Demeter, the Greek goddess of grain. She owed her installation in Rome to the influence of the Greek colony of Cumae, from which the Romans imported grain during a threatened famine. The association of Ceres at this temple with two other deities, Liber (a fertility god identified with Dionysus) and Libera (his female counterpart), was based on the triad at Eleusis in Greece. The Roman temple, built in the Etruscan style but with Greek ornamentation, stood beside a Greek trading centre on the Aventine Hill and became a rallying ground for the plebeians, the humbler section of the community who were hard hit by the grain shortage at this time and who were pressing for their rights against the patricians.

Ceres, Apollo, and Venus

Cumae also played a part in the introduction of Apollo. The Sibylline oracles housed in Apollo's shrine at Cumae allegedly were brought to Rome by the last Etruscan kings. The importation of the cult (431 BC) was prescribed by the Sibylline Books at a time when Rome, as on earlier occasions, had requested Cumae for help with grain. The Cumaean Apollo, however, was primarily prophetic, whereas the Roman cult, introduced at a time of epidemic, was concerned principally with his gifts as a healer. This role may possibly have been derived from the Etruscans, whose Apollo is known from a superb statue of *c.* 500 BC from Veii, Etruria's nearest city to Rome. In 82 BC the Sibylline Books were destroyed and replaced by a collection assembled from various sources. Later, Augustus elevated Apollo as the patron of himself and his regime, intending thereby to convert the brilliant Hellenic god of peace and civilization to the glory of Rome.

Unlike Apollo, Aphrodite did not keep her name when she became identified with an Italian deity. Instead, she took on the name Venus, derived, without complete certainty, from the idea of *venus,* "blooming nature" (the derivation from *venia,* "grace," seems less likely). She gained greatly in significance because of the legend that she was the mother of Aeneas, the ancestor of Rome, whom statuettes of the 5th century BC from Veii show escaping from Troy with his father and son. From the time of the Punic Wars 200 years later the Trojan legend grew, for long before the 1st-century-BC dictators Sulla and Caesar claimed Venus as their ancestor, the story was interpreted as the preface to the Carthaginian struggle.

A number of gods were spoken of as possessing accompaniments, often in the feminine gender; *e.g.,* Lua Saturni and Moles Martis. These attachments, sometimes spoken of as cult partners, were not the wives of the male divinities but rather expressed a special aspect of their power or will. A similar origin could be ascribed to the worship of divine powers representing "qualities." Fides ("Faith" or "Loyalty"), for example, may at first have been an attribute or aspect of a Latin-Sabine god of oaths, Semo Sanctus Dius Fidius; and in the same way Victoria may come from Jupiter Victor. Some of these concepts were worshiped very early, such as Ops ("Plenty," later associated with Saturn and equated with Hebe), and Juventas (who watched over the men of military age). The first of these qualities to receive a temple, as far as is known, is Concordia (367), in celebration of the end of civil strife. Salus (health or well-being) followed in *c.* 302, Victoria in *c.* 300, Pietas (dutifulness to family and gods, later exalted by Virgil as the whole basis of Roman religion) in 191. The Greeks, too, from the earliest days, had clothed such qualities in words; *e.g.,* Shame, Peace, Justice, and Fortune. In the Hellenic world they had a wide variety of signification, ranging from full-fledged divinity to nothing more than abstractions. But in early Rome and Italy they were in no sense abstractions or allegories and were likewise not thought of as possessing the anthropomorphic shape that the term personification might imply. They were things, objects of worship, like many other functions that were venerated. They were external divine forces working upon humans and affecting them with the qualities that their names described. Later on, under philosophical (particularly Stoic) influences that flooded into ethically minded Rome, they duly took their place as moral concepts, the Virtues and Blessings which abounded for centuries and were depicted in human form on Roman coinage as part of the imperial propaganda.

Divine qualities

The Sun and stars. Little or no contribution to cosmology was made in the Roman world, and the demonstration of Aristarchus of Samos (*c.* 270 BC) that the Earth revolves around the Sun received virtually no support. The complicated geocentric interpretation that held sway in Rome was summed up in Cicero's *Dream of Scipio.* It formed the basis for the concept of the solar system on which the popular pseudoscience of astrology was founded, the Sun being regarded as the centre of the concentric planetary spheres encircling the Earth—not the centre of the cosmos in the sense of Aristarchus but its heart. From the 5th century BC onward this solar god was identified with Apollo in his role as the supreme dispenser of agricultural wealth. Possessor of a sacred grove at Lavinium, Sol Indiges was regarded as one of the divine ancestors of Rome. During the last centuries before the Christian era, worship of the Sun spread throughout the Mediterranean world and formed the principal rallying point of paganism's last years. Closely associated with the sun cult was that of Mithra, the Sun's ally and agent who was elevated to partake of communion and the love feast as

Sol

the god's companion. Sun worship was popular in the army, and particularly on the Danube. Aurelian, one of the great military emperors produced by that area in the 3rd century, built a magnificent temple of Sol Invictus (the "Unconquered Sun") at Rome (274). Constantine the Great declared the Sun his Comrade on empire-wide coinages and devoted himself to the cult until he adopted Christianity in its stead.

The *rex sacrorum, flamines,* and colleges of priests

Priests. Precedence among Roman priests belonged to the *rex sacrorum* ("king of the sacred rites"), who, after the expulsion of the kings, took over the residue of their religious powers and duties that had not been assumed by the Republican officers of state. Nevertheless, the hold exercised by the *rex sacrorum* and his colleagues was weakened by the Law of the Twelve Tables (*c.* 451–450 BC), which displayed the secular arm exercising some control over sacral law. As late as *c.* 275 BC the religious calendar was still dated by the *rex sacrorum,* but by this time he was already fading into the background.

Very early origins can also be attributed to some of the *flamines,* the priests of certain specific cults, and particularly to the three major *flamines* of Jupiter, Mars, and Quirinus. Jupiter's priest, the *flamen dialis,* was encompassed by an extraordinary series of taboos, some dating to the Bronze Age, which made it difficult to fill the office in historic times.

Except for the *rex sacrorum* and *flamen dialis,* whose duties were unusually professional and technical, almost all Roman priesthoods were held by men prominent in public life. The social distinction and political prestige carried by these part-time posts caused them to be keenly fought for.

There were four chief colleges, or boards, of priests: the *pontifices, augures, quindecimviri sacris faciundis,* and *epulones.* Originally three, and finally 16 in number, the *pontifices* (whose name may recall antique tasks and magic rites in connection with bridges) had assumed control of the religious system by the 3rd century BC. The chief priest, the *pontifex maximus* (the head of the state clergy), was an elected official and not chosen from the existing *pontifices.* The *augures,* whose name may have been derived from the practice of magic in fertility rites and perhaps meant "increasers," had the task of discovering whether or not the gods approved of an action. This they performed mainly by interpreting divine signs in the movements of birds (*auspicia*). Such divination was elevated, perhaps under Etruscan influence, into an indispensable preliminary to state acts, though the responsibility for the decision rested not with the priests but with the presiding state officials, who were said to "possess the auspices." In private life too, even as late as Cicero and Horace in the 1st century BC, important courses of action were often preceded by consultation of the heavens. The Etruscan method of divining from the liver and entrails of animals (*haruspicina*) became popular in the Second Punic War, though its practitioners (who numbered 60 under the empire) never attained an official priesthood.

Of the other two major colleges, the *quindecimviri* ("Board of Fifteen," who earlier had been 10 in number) *sacris faciundis* looked after foreign rites, and the members of the other body, the *epulones,* supervised religious feasts. There were also *fetiales,* priestly officials who were concerned with various aspects of international relationships, such as treaties and declarations of war. Also six Vestal Virgins, chosen as young girls from the old patrician families, tended the shrine and fire of Vesta and lived in the House of Vestals nearby, amid a formidable array of prehistoric taboos.

Annual festivals

Shrines and temples. The Roman calendar, as introduced or modified in the period of the Etruscan kings, contained 58 regular festivals. These included 45 Feriae Publicae, celebrated on the same fixed day every year, as well as the Ides of each month, which were sacred to Jupiter, and the Kalends of March, which belonged to Mars. Famous examples of Feriae Publicae were the Lupercalia (February 15) and Saturnalia (December 17, later extended). There were also the Feriae Conceptivae, the dates of which were fixed each year by the proper authority, and which included the Feriae Latinae ("Latin Festival") celebrated in the Alban Hills, usually at the end of April.

Templum is a term derived from Etruscan divination. First of all, it meant an area of the sky defined by the priest for his collection and interpretation of the omens. Later, by a projection of this area onto the earth, it came to signify a piece of ground set aside and consecrated to the gods. At first such areas did not contain sacred buildings, but there often were altars on such sites, and later shrines. In Rome, temples have been identified from *c.* 575 BC onward, including not only the round shrine of Vesta but also a group in a sacred area (S. Omobono), close to the river Tiber beside the cattle market (Forum Boarium). The great Etruscan temples, made of wood with terra-cotta ornaments, were constructed later and culminated in the temple of the Capitoline Triad. Subsequently, more solid materials, such as tuff (tufa), travertine, marble, cement, and brick, gradually came into use. Temple archives, now vanished, play a large part in the historical tradition, and the anniversaries of the vows to build the temples and their dedication were scrupulously remembered and celebrated on numerous coins.

Sacrifice and burial rites. The characteristic offering of the Romans was a sacrifice accompanied by a prayer or vow. (The Triumph, associated with Jupiter, was regarded as a thanksgiving in discharge of a vow.) Animal sacrifices were regarded as more effective than anything else, the pig being the commonest victim, with sheep and ox added on important occasions. Considered best of all were the basic elements of life: heart, liver, and kidneys. Human sacrifice, on the whole, was extraneous to Roman custom, though its practice among the Etruscans may have contributed to the institution of gladiatorial funeral games in both Etruria and Rome, and it was resorted to in major crises, notably during the Second Punic War (216 BC). Earlier in the century, and perhaps once before, a member of the family of the Decii had given up his life by self-sacrifice (*devotio*) in a critical battle.

Although ancestors were meticulously revered, there was nothing resembling the comprehensive Etruscan attention to the dead. In spite of elaborate philosophizing by Cicero and Virgil about the possibility of some sort of survival of the soul (especially for the deserving), most Romans' ideas of the afterlife, unless they believed in the promises of the mystery religions, were vague. Such ideas often amounted to a cautious hope or fear that the spirit in some sense lived on, and this was sometimes combined with an anxiety that the ghosts of the dead, especially the young dead who bore the living a grudge, might return and cause harm. Graves and tombs were inviolable, protected by supernatural powers and by taboos. In the earliest days of Rome both cremation and inhumation were practiced simultaneously, but by the 2nd century BC the former had prevailed. Some 300 years later, however, there was a massive reversion to inhumation, probably because of an inarticulate revival of the feeling that the future welfare of the soul depended on comfortable repose of the body—a feeling that, as sarcophagi show, was fully shared by the adherents of the mystery cults, though, on the rational level, it contradicted their assurance of an afterlife in some spiritual sphere. The designs on these tombs reflect the soul's survival as a personal entity that has won its right to paradise.

Cremation and inhumation

Religious art. A vast gallery of architecture, sculpture, numismatics, painting, and mosaics illustrates Roman religion and helps to fill the gaps left by the fragmentary, though extensive, literary and epigraphic record. Starting with primitive statuettes and terra-cotta temple decorations, this array eventually included masterpieces such as the Apollo of Veii. Other works of art, more than 400 years later, include paintings illustrating Dionysiac mysteries at Boscoreale near Pompeii, and the reliefs of Augustus' Ara Pacis at Rome; and with the Christian emblems of Constantinian sarcophagi and coinage a thousand years of ancient Roman religious art comes to an end.

CONCLUSION

Though Roman religion never produced a comprehensive code of conduct, its early rituals of house and farm engen-

dered a feeling of duty and unity. Its idea of reciprocal understanding between man and god not only imparted the sense of security that Romans needed in order to achieve their successes but stimulated, by analogy, the concept of mutual obligations and binding agreements between one person and another. Except for rare aberrations, such as human sacrifice, Roman religion was unspoiled by orgiastic rites and savage practices. Moreover—unlike ancient philosophy—it was neither sectarian nor exclusive. It was a tolerant religion, and it would be difficult to think of any other whose adherents committed fewer crimes and atrocities in its name. (M.Gr.)

Hellenistic religions

The period of Hellenistic influence (which extended roughly from 300 BC to AD 300), when taken as a whole, constitutes one of the most creative periods in the history of religions. It was a time of spiritual revolution in the Greek and Roman empires, when old cults died or were fundamentally transformed and when new religious movements came into being.

NATURE AND SIGNIFICANCE

The historical Hellenistic Age is defined as the period from the death of the Greco-Macedonian conqueror Alexander the Great (323 BC) to the conquest of Egypt by Rome (30 BC), but the influence of the Hellenistic religions extended to the time of Constantine, the first Christian Roman emperor (d. AD 337); these religions are confined to those that were active within the Mediterranean world. The empire of Alexander and his successors created a great world community which, whether in Macedonian, Greco-Roman, or its later Christian form, established a cultural unity that was destined to be broken only 1,000 years later with the advent of Muslim imperialism (beginning in 7th century AD). This empire was so vast as truly to stagger the imagination. Extending from the Strait of Gibraltar to the Indus River, from the forests of Germany and the steppes of Russia to the Sahara Desert and the Indian Ocean, it took in an area of some 1.5 million square miles (3.9 million square kilometres; most of Europe, the Mediterranean, the Middle East, Africa, Persia, and the borderlands of India) and had a total population of more than 54 million.

The dispersion of local and area cults and the resultant changes

The study of Hellenistic religions is a study of the dynamics of religious persistence and change in this vast and culturally varied area. Almost every religion in this period occurred in both its homeland and in diasporic centres—the foreign cities in which its adherents lived as minority groups. For example, Isis (Egypt), Baal (Syria), the Great Mother (Phrygia), Yahweh (Palestine), and Mithra (Kurdistan) were worshiped in their native lands as well as in Rome and other cosmopolitan centres. With few exceptions, each of these religions, originally tied to a specific geographic area and people, had traditions extending back centuries before the Hellenistic period. In their homeland they were inextricably tied to local loyalties and ambitions. Each persisted in its native land with little perceptible change save for its becoming linked to nationalistic or messianic movements (centring on a deliverer figure) seeking to overthrow Greco-Roman political and cultural domination. Indeed, many of these native religions underwent a conscious archaism during this period, attempting to recover earlier forms and practices. Old texts in native languages (especially those related to relevant themes such as kingship) were recopied, national temples were restored, and old, mythic traditions were revived. From Palestine to Persia one may trace the rise of Wisdom literature (the teachings of a sage concerning the hidden purposes of the deity) and apocalyptic traditions (referring to a belief in the dramatic intervention of a god in human and natural events) that represent these central concerns—*i.e.*, national destiny, the importance of traditional lore, the saving power of kingship, and the revival of mythic images. Each of these native traditions likewise underwent hellenization (modifications based on Greek cultural ideas), but in a manner frequently different from their diasporic counterparts.

Each of these native religions also had diasporic centres that exhibited marked change during the Hellenistic period. There was a noticeable lessening of concern on the part of the members of the dispersed religious group for the destiny and fortunes of the native land and also a relative severing of the traditional ties between religion and the land. Certain cult centres remained sites of pilgrimage or objects of sentimental attachment; but the old beliefs in national deities and the inextricable relationship of the deity to certain sacred places was weakened. Rather than a god who dwelt in his temple, the diasporic traditions evolved complicated techniques for achieving visions, epiphanies (manifestations of a god), or heavenly journeys to a transcendent god. This led to a change from concern for a religion of national prosperity to one for individual salvation, from focus on a particular ethnic group to concern for every human. The prophet or saviour replaced the priest and king as the chief religious figure. In the diasporic centres, as is generally characteristic of immigrant groups, there were two circles. The first (or inner circle) was composed of devout, full-time adherents of the cult for whom the deity retained a separate and decisive identity (*e.g.*, those of Yahweh, Zeus Sarapis, and Isis). Its membership was drawn from the ethnic group for whom the deity was indigenous, and the group tended to continue to speak the native language. The second (or outer circle) was composed of either second- and third-generation immigrants or converts from groups for whom the religion was not native. These individuals tended to speak Greek, and this began the lengthy process of reinterpretation of the archaic religion. Ancient sacred books were translated or paraphrased into Greek—*e.g.*, the 4th–3rd-century-BC Babylonian priest Berosus' version of Babylonian materials, the 4th–3rd-century-BC Egyptian priest Manetho's Egyptian accounts, the Jewish Septuagint (Greek version of the Old Testament), or the 1st-century-AD Jewish historian Josephus' *Antiquities of the Jews,* and the ethnic histories of the 1st-century-BC Greek writer Alexander Polyhistor. In each case the material was reinterpreted both in light of common Hellenistic ideals and in accord with the special traditions and needs of the diasporic community. Both the inner and outer circles fostered esotericism (secrets to be known only by initiates)—the former by its use of native language and its oral recollection of traditions from the homeland; the latter by its use of allegory and other similar methods to radically reinterpret the sacred texts. The difference between these groups was responsible for many shifts in the character of the religion. Most notable was the shift from elements characteristic of native religion in its definition of religion (*e.g.*, local tradition and custom, informal knowledge orally transmitted, and birth) to formulated dogma, creeds, law codes, and rules for conversion and admission that were characteristic of diasporic religion. It was a shift from "birthright" to "convinced" religion.

The history of Hellenistic religions is rarely the history of genuinely new religions. Rather it is best understood as the study of archaic Mediterranean religions in their Hellenistic phase within both their native and diasporic settings. It is usually by concentrating on the diaspora that the Hellenistic character of a cult has been described.

HISTORY

Religion from the death of Alexander to the reformation of Augustus: 323–27 BC. The conquests of Alexander opened the way for religious interchange between East and West; the political structures left behind by Alexander and continued by his successors provided strong incentives for the hellenization of native religions. Characteristic of this first period of Hellenistic religious history were the following developments: (1) the introduction of Oriental cults into the West, especially those associated with female deities who were either worshiped in frenzied rites of self-mutilation (*e.g.*, the Phrygian Cybele, brought to Rome in 204 BC; the Syrian Atargatis; or the Cappadocian Ma-Bellona) or in adoring contemplation of their beneficence and gentle rites of divine rebirth (*e.g.*, the Egyptian Isis, whose cult was widespread in the Greco-Roman world by the middle of the 2nd century BC); (2) the hellenization

Religious interchange between East and West

of native cults (most famously that of the archaic Egyptian god Sarapis whose Greek form was promulgated by Ptolemy I, the founder of the Egyptian Ptolemaic dynasty in 305 BC); (3) the development of the ideology of divine kingship based on Oriental kingship traditions; and (4) the rise of nationalistic and messianic movements directed against internal and external hellenization; *e.g.*, the Maccabean rebellion led by Judas Maccabeus against Jewish hellenizing parties and the Syrian overlords in 167–165 BC, and the numerous Egyptian rebellions, especially that led by the Egyptian independence leader Harmakhis in Thebais in 207/6 BC.

Religion from the Augustan reformation to the death of Marcus Aurelius: 27 BC–AD 180. Oriental cults underwent their most significant expansion westward during this period. Particularly noticeable was the success of a variety of prophets, magicians, and healers—*e.g.*, John the Baptist, Jesus, Simon Magus, Apollonius of Tyana, Alexander the Paphlagonian, and the cult of the healer Asclepius—whose preaching corresponded to the activities of various Greek and Roman philosophic missionaries. A developing tension between these "new" Eastern religions and the archaic Greco-Roman traditions was expressed internally in the attempt by the emperor Augustus to revive traditional Roman religious practices. Attempts were made to expel foreigners or to suppress foreign worship—*e.g.*, the suppression of the Bacchic mysteries (salvation cults devoted to the god Dionysus, or Bacchus) in Rome in 186 BC, or the numerous attempts to prohibit the worship of the Egyptian goddess Isis in Rome, beginning in 59 BC. The Augustan reformation also restored Roman sacred books and Greek temples.

Developing tensions between the Greco-Roman and the Eastern religions

Externally, the developing tension was expressed in wars, riots, and persecutions, such as the Jewish–pagan riots in Alexandria in AD 38 and 115–116, the Jewish–Roman wars of AD 66–70 and 132–135, and the beginning of the persecution of Christians under the Roman emperor Nero in AD 64. Another cause of tension was the elaboration of a full-blown cult of "emperor worship," beginning with the deification of Augustus (Sept. 17, AD 14) shortly after his death.

Religion from Commodus to Theodosius I: AD 180–395. After the death of the "philosopher-king" Marcus Aurelius in AD 180, his son Commodus became emperor, and a period of political instability began. The dominant feature of the concluding period of Hellenistic influence—and shortly thereafter—was the rapid growth of Christianity throughout the Roman Empire, culminating in the conversion to Christianity of the emperor Constantine in 313 and the religious legislation of the emperor Theodosius affirming in 380 the dogmas of the Christian Council of Nicaea—which had been convened in 325 under the auspices of Constantine—and prohibiting paganism in a decree of 392. In this period the various Hellenistic cults were victims of active hostilities, which were expressed through prohibition, acts of violence, and theological polemics between "pagans" and Christians (*e.g.*, the pagan philosophers Maximus of Tyre and Celsus, and the Christian philosophical theologians Irenaeus, Tertullian, and St. Clement of Alexandria, all of the 2nd century); but there were also brief periods of Hellenistic revitalization. The Neoplatonic school (based on a complicated system of levels of reality) of the 3rd-century philosophers Plotinus and Porphyry represented the culmination of Hellenistic religious philosophy. The Syrian solar cults of Sol Invictus (the "Unconquered Sun") and Jupiter Dolichenus played an important role under the emperors Antoninus Pius, the Severans—Septimius, and Alexander—and Elagabalus and these were hailed as the supreme deities of Rome under Aurelian, whose Sun temple was dedicated in 274. From Parthia, the dualistic and spiritual teachings of the 2nd-century Iranian prophet Mani were widely disseminated throughout the Empire. The Persian cult of the ancient Iranian god of light, Mithra, spread rapidly throughout the western and northern Empire during the 3rd through 5th centuries. Although these various traditions enjoyed brief imperial patronage under Julian, they eventually were subsumed under the political and religious hegemony of Christianity (see below).

BELIEFS, PRACTICES, AND INSTITUTIONS

The archaic religions of the Mediterranean world were primarily religions of etiquette. At the centre of these religions were complex systems governing the interrelationships between gods and humans, individuals and the state, and living people and their ancestors. The entire cosmos was conceived as a vast network of relationships, each component of which, whether divine or human, must know its place and fulfill its appointed role. The model for this all-encompassing system was the divine society of the gods, and the map of this system was the order of the planets and stars. Through astrology, divination, and oracles, people discerned the unalterable patterns of destiny and sought to bring their world (the microcosm) into harmony with the divine cosmos (the macrocosm; see also OCCULTISM: *Divination: astrology*).

The centrality of the relationship between the gods and men

Cincinnati Art Museum, Museum Purchase



Limestone relief of the goddess Tyche in a zodiac, 2nd century AD. In the Cincinnati Art Museum.

This archaic pattern of affirming and celebrating the order of the cosmos was expressed in the typical creation myth of the Middle Eastern and Mediterranean world, which consisted of a creation by combat between the forces of order and chaos. Order was understood to be something won in the beginning by the gods, and it was this primordial act of salvation that was renewed and re-experienced in the cult.

In the Hellenistic period a new religious world was experienced that required new religious expressions. The old religions of conformity and place no longer spoke to this new religious situation and its questions. What if the law and order of the cosmos was no longer seen as the creative expression of limits and the delineation of roles, but rather as an evil, perverse, confining structure from which man and the cosmos must escape? Rather than the archaic structures of celebration and conformity to place, the new religious mood spoke of escape and liberation from place and of salvation from an evil, imprisoned world. The characteristic religion of the Hellenistic period was dualistic. People sought to escape from the despotism of this world and its rulers (exemplified by the seven planetary spheres) and to ascend to another world of freedom. Hellenistic people saw themselves as exiles from their true home, the Beyond, and they sought for ways to return. They strove to regain their place in the world beyond this world where they truly belonged, to encounter the god beyond the god of this world who was the true god, and to awaken that part of themselves (their souls or spirits) that had descended from the heavenly realm by stripping off their bodies, which belonged to this world. The questions that the religions of the Hellenistic period sought to answer may be seen in a fragment from the 2nd-century Anatolian Gnostic teacher Theodotus: "What liberates is the

Salvation as liberation through knowledge of one's origin, identity, and destiny

knowledge of who we were [before our earthly existence] and what we have become [on earth]; where we were [the Beyond] and the place to which we have been thrown [the world]; where we are going and from what are we redeemed; what is birth and what is rebirth" (preserved in Clement of Alexandria, *Excerpta ex Theodoto*, 78.2).

The gods. In the Greco-Roman world during the Hellenistic period, archaic deities were transformed in part because of the new spirit of the age and in part by foreign influences. A number of the old chthonic (underworld) and agricultural (fertility) gods and the old agricultural mysteries (corporate renewal religions related to fertility concepts) fundamentally altered their character. Rather than an expression of the alternation of life and death, of fertility and sterility, and a celebration of the promise of renewal for the land and the people, the seasonal drama was homologized to a soteriology (salvation concept) concerning the destiny, fortune, and salvation of the individual after death. The collective agricultural rite became a mystery, a salvific experience reserved for the elect (such as the Greek mystery religion of Eleusis). Other traditions even more radically reinterpreted the ancient figures. The cosmic or seasonal drama was interiorized to refer to the divine soul within man that must be liberated. Such cults were dualistic mysteries distinguishing sharply between the body and soul. They taught that it is the soul alone that was initiated by passing through death or the Underworld, or by being dismembered so that it might be freed from the body and regain its rightful mode of spiritual existence (such as the Orphic—mystical—reinterpretation of the role of the agricultural god Dionysus). In the gnostic mysteries (the esoteric dualistic cults that viewed matter as evil and the spirit as good), this process was carried further through the identification of the experiences of the soul that was to be saved with the vicissitudes of a divine but fallen soul, which had to be redeemed by cultic activity and divine intervention. This view is illustrated in the concept of the paradoxical figure of the saved saviour, *salvator salvandus.*

Other deities, who had previously been associated with national destiny (*e.g.*, Zeus, Yahweh, and Isis), were raised to the status of transcendent, supreme deities whose power and ontological status (relating to being or existence) far surpassed the other gods, who were understood as their servants or antagonists. The religious person sought to make contact with, or to stand before, this one, true god of the Beyond. The piety of the individual was directed either toward preparing himself to ascend up through the planetary spheres to the realm of the transcendent god or toward calling the transcendent god down that he might appear to him in an epiphany or vision. These techniques for achieving ascent or a divine epiphany make up the bulk of the material that has usually been termed magical, theurgic (referring to the art of persuading a god to reveal himself and grant salvation, healing, and other requests), or astrological and that represents the characteristic expression of Hellenistic religiosity.

Individual piety

Cosmogony and cosmology. The cosmogonies (dealing with the origins of the world) and cosmologies (dealing with the ordering of the world) of the Hellenistic period centred around the problem of accounting for the distance between this world and the Beyond, or on accounting for the evil nature of this world and its gods. Many mythic schema were employed regarding the origin and ordering of this world. It was viewed as being: the result of the conscious or unconscious emanation from the transcendent realm; the result of the fall of a deity from the Beyond; the creation of a hostile, ignorant, or evil deity; or a joke or mistake. The purpose of this speculation was both pragmatic and soteriological: if one could determine how this creation came into being, one could reverse it or overcome it and be saved.

Religious organization. The temples and cult institutions of the various Hellenistic religions were repositories of the knowledge and techniques necessary for salvation and were the agents of the public worship of a particular deity. In addition, they served an important sociological role. In the new, cosmopolitan ideology that followed Alexander's conquests, the old nationalistic and ethnic boundaries had broken down and the problem of religious and social identity had become acute. The Hellenistic Age was characterized by the rapid growth of private religious societies (*thiasoi*). Though some were organized according to national origin or trade, the majority were dedicated to the worship of a particular deity. In many instances these groups began as immigrant associations (*e.g.*, an Egyptian association of devotees of Amon was chartered in Athens at the beginning of the 3rd century BC); but they often transcended these origins and became a new form of religious organization in which citizens of various countries, freemen and slaves, could be united by their common devotion and share in a common religious heritage. Admission to such groups was voluntary (in contradistinction to the archaic national or familial religious organizations) and demanded the payment of dues, submission to collective authority, and the acceptance of strict codes of morality. Most of these groups had regular meetings for a communal meal that served the dual role of sacramental participation (referring to the use of material elements believed to convey spiritual benefits among the members and with their deity) and the social function of fellowship; *i.e.*, the security of membership in a group and a shared sense of identity.

Hellenistic religions as voluntary associations

THE INFLUENCE OF HELLENISTIC RELIGIONS

The archaic gods worshiped during the Hellenistic period possessed a remarkable longevity. The Eleusinian Mysteries, founded in the 15th century BC, ceased in the 4th century AD; Dionysus, whose name first appears on tablets dated to *c.* 1400 BC, was last celebrated in the beginning of the 6th century AD; the last temple of Isis, whose cult extended back to the 2nd millennium BC in Egypt, was closed in AD 560. Yet even after these ceased as objects of devotion in the post-Constantinian period, they continued to exercise their influence. Hellenistic philosophy (Stoicism, Cynicism, Neo-Aristotelianism, Neo-Pythagoreanism, and Neoplatonism) provided key formulations for Jewish, Christian, and Muslim philosophy, theology, and mysticism through the 18th century. Hellenistic magic, theurgy, astrology, and alchemy remained influential until modern times in both East and West. Theosophy and other forms of the occult, especially since the Renaissance, drew their inspiration from the Hellenistic mystery cults, Hermeticism (Greco-Egyptian astrological, magical, and occultic movement), and Gnosticism. Various Jewish, Christian, and Muslim sectarian groups continued the theologies of many of the Hellenistic religions (especially dualistic modes of thought). Hellenistic sacred art and architecture has remained a basis of Christian and Jewish iconography and architecture to the present day. Figures such as Alexander the Great inspired a vast body of religious literature, especially in the Middle Ages. Many of the symbols and legends associated with Hellenistic deities persisted in folk literature and hagiography (stories of saints and "holy" persons). The basic forms of worship of both the Jewish and Christian communities were heavily influenced in their formative period by Hellenistic practices, and this remains fundamentally unchanged to the present time. Finally, the central religious literature of both traditions—the Jewish Talmud (an authoritative compendium of law, lore, and interpretation), the New Testament, and the later patristic literature of the early Church Fathers—are characteristic Hellenistic documents both in form and content. (J.Z.S.)

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Mount Everest

Mount Everest, the crowning peak on the crest of the Great Himalayas of southern Asia, lies on the border between Nepal and the Tibet Autonomous Region of China, at 27°59′ N, 86°56′ E. Reaching an elevation of 29,035 feet (8,850 metres), it is the highest mountain in the world and the highest point on Earth.

Like other high peaks in the region, Mount Everest has long been revered by local peoples. Its most common Tibetan name, Chomolungma—rendered in Chinese as (Wade-Giles) Chu-mu-lang-ma Feng or (Pinyin) Zhumulangma Feng—means "Goddess Mother of the World" or "Goddess of the Valley." The Sanskrit and Nepali name, Sāgarmāthā, means literally "Ocean Mother." Its identity as the Earth's highest point was not recognized, however, until 1852, when the governmental Survey of India established that fact. In 1865 the mountain—previously referred to as Peak XV—was renamed for Sir George Everest, British surveyor general of India from 1830 to 1843.

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Physical features

GEOLOGY AND RELIEF

The Himalayan ranges were thrust upward by tectonic action as the Indian-Australian Plate moved northward from the south and was subducted (forced downward) under the Eurasian Plate following the collision of the two plates about 50 million years ago. The Himalayas themselves started rising about 25 to 30 million years ago, and the Great Himalayas began to take their present form during the Pleistocene Epoch (about 1,600,000 to 10,000 years ago). Everest and its surrounding peaks are part of a large mountain massif that forms a focal point, or knot, of this tectonic action in the Great Himalayas. Information from global positioning instruments in place on Everest since the late 1990s indicates that the mountain continues to move a few inches to the northeast and rise a fraction of an inch each year.

Rock composition

Everest is composed of multiple layers of rock folded back on themselves (nappes). Rock on the lower elevations of the mountain consists of metamorphic schists and gneisses, topped by igneous granites. Higher up are found sedimentary rocks of marine origin (remnants of the ancient floor of the Tethys Sea that closed after the collision of the two plates). Notable is the Yellow Band, a limestone formation that is prominently visible just below the summit pyramid.

The barren Southeast, Northeast, and West ridges culminate in the Everest summit; a short distance away is the South Summit, a minor bump on the Southeast Ridge with an elevation of 28,700 feet (8,748 metres). The mountain can be seen directly from its northeastern side, where it rises about 12,000 feet above the Plateau of Tibet. The peak of Changtse (24,803 feet [7,560 metres]) rises to the north. Khumbutse (21,867 feet [6,665 metres]), Nuptse (25,791 feet [7,861 metres]), and Lhotse (27,923 feet [8,511 metres]) surround Everest's base to the west and south.

Everest is shaped like a three-sided pyramid. The three generally flat planes constituting the sides are called faces, and the line by which two faces join is known as a ridge. The North Face rises above Tibet and is bounded by the North Ridge (which meets the Northeast Ridge) and the West Ridge; key features of this side of the mountain include the Great and Hornbein couloirs (steep gullies) and the North Col at the start of the North Ridge. The Southwest Face rises above Nepal and is bounded by the West Ridge and the Southeast Ridge; notable features on this side include the South Col (at the start of the Southeast Ridge) and the Khumbu Icefall, the latter a jumble of large blocks of ice that has long been a daunting challenge for climbers. The East Face—or Kangshung Face—also rises above Tibet and is bounded by the Southeast Ridge and the Northeast Ridge.

The summit of Everest itself is covered by rock-hard snow

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The North Face of Mount Everest, seen from the Rong River valley, Tibet.

surmounted by a layer of softer snow that fluctuates annually by some 5–20 feet; the snow level is highest in September, after the monsoon, and lowest in May, after having been depleted by the strong northwesterly winter winds. The summit and upper slopes sit so high in the Earth's atmosphere that the amount of breathable oxygen there is one-third what it is at sea level. Lack of oxygen, powerful winds, and extremely cold temperatures preclude the development of any plant or animal life there.

DRAINAGE AND CLIMATE

Glaciers cover the slopes of Everest to its base. Individual glaciers flanking the mountain are the Kangshung Glacier to the east; the East, Central, and West Rongbuk (Rongpu) glaciers to the north and northwest; the Pumori Glacier to the northwest; and the Khumbu Glacier to the west and south, which is fed by the glacier bed of the Western Cwm, an enclosed valley of ice between Everest and the Lhotse-Nuptse Ridge to the south. Glacial action has been the primary force behind the heavy and continuous erosion of Everest and the other high Himalayan peaks.

The mountain's drainage pattern radiates to the southwest, north, and east. The Khumbu Glacier melts into the Lobujya (Lobuche) River of Nepal, which flows southward as the Imja River to its confluence with the Dudh Kosi River. In Tibet the Rong River originates from the Pumori and Rongbuk glaciers and the Kama River from the Kangshung Glacier: both flow into the Arun River, which cuts through the Himalayas into Nepal. The Rong, Dudh Kosi, and Kama river valleys form, respectively, the northern, southern, and eastern access routes to the summit.

Temperatures

The climate of Everest is always hostile to living things. The warmest average daytime temperature (in July) is only about −2° F (−19° C) on the summit; in January, the coldest month, summit temperatures average −33° F (−36° C) and can drop as low as −76° F (−60° C). Storms can come up suddenly, and temperatures can plummet unexpectedly. The peak of Everest is so high that it reaches the lower limit of the jet stream, and it can be buffeted by sustained winds of more than 100 miles (160 km) per hour. Precipitation falls as snow during the summer monsoon (late May to mid-September). The risk of frostbite to climbers on Everest is extremely high.

THE HEIGHT OF EVEREST

Controversy over the exact elevation of the summit developed because of variations in snow level, gravity deviation, and light refraction. The figure 29,028 feet (8,848 metres), plus or minus a fraction, was established by the Survey of India between 1952 and 1954 and became widely accepted. This value was used by most researchers, mapping agencies, and publishers until 1999.

Attempts were subsequently made to remeasure the mountain's height. A Chinese survey in 1975 obtained the figure of 29,029.24 feet (8,848.11 metres), and an Italian survey, using satellite surveying techniques, obtained a value of 29,108 feet (8,872 metres) in 1987, but questions arose about the methods used. In 1992 another Italian survey, using the Global Positioning System (GPS) and laser measurement technology, yielded the figure 29,023 feet (8,846 metres) by subtracting from the measured height 6.5 feet of ice and snow on the summit, but the methodology used was again called into question.

In 1999 an American survey, sponsored by the (U.S.) National Geographic Society and others, took precise measurements using GPS equipment. Their finding of 29,035 feet, plus or minus 6.5 feet, was accepted by the society and by various specialists in the fields of geodesy and cartography.

HUMAN FACTORS

Habitation. Everest is so tall and its climate so severe that it is incapable of supporting sustained human occupation, but the valleys below the mountain are inhabited by Tibetan-speaking peoples. Notable among these are the Sherpas, who live in villages at elevations up to about 14,000 feet in the Khumbu valley of Nepal and other locations. Traditionally an agricultural people with little cultivable land at their disposal, the Sherpas for years were traders and led a seminomadic lifestyle in their search for pastureland. In summer, livestock was grazed as high as 16,000 feet, while winter refuge was taken at lower elevations on sheltered ledges and along riverbanks.

Sherpa beliefs

Living in close proximity to the world's highest mountains, the Sherpas traditionally treated the Himalayas as sacred—building Buddhist monasteries at their base, placing prayer flags on the slopes, and establishing sanctuaries for the wildlife of the valleys that included musk deer, monal pheasant, and Himalayan partridge. Gods and demons were believed to live in the high peaks, and the Yeti (the so-called Abominable Snowman) was said to roam the lower slopes. For these reasons, the Sherpas traditionally did not climb the mountains.

However, beginning with the British expeditions of the early 20th century, surveying and portering work became available. Eventually, the respect and pay earned in mountaineering made it attractive to the Sherpas, who, being so well adapted to the high altitudes, were capable of carrying large loads of cargo over long distances. Though Sherpas and other hill people (the name Sherpa came to be applied—erroneously—to all porters) tend to outperform their foreign clients, they typically have played a subordinate role in expeditions; rarely, for example, has one of their names been associated with a pioneering route on Everest. The influx of foreign climbers—and, in far greater numbers, trekkers—has dramatically changed Sherpa life, as their livelihood increasingly has come to depend on these climbing expeditions.

Environmental concerns. On the Nepalese side of the international boundary, the mountain and its surrounding valleys lie within Sāgarmāthā National Park, a 480-square-mile (1,243-square-kilometre) zone established in 1976. In 1979 the park was designated a UNESCO World Heritage site. The valleys contain stands of rhododendron and forests of birch and pine, while above the tree line alpine vegetation extends to the feet of the glaciers. Over the years, carelessness and excessive consumption of resources by mountaineers, as well as overgrazing by livestock, have damaged the habitats of snow leopards, lesser pandas, Tibetan bears, and scores of bird species. To counteract past abuses, various reforestation programs have been carried out by local communities and the Nepalese government. Expeditions have removed supplies and equipment left by climbers on Everest's slopes, including hundreds of oxygen containers. Most of the litter of past climbers—tons of items such as tents, cans, crampons, and human waste—has been hauled down from the mountain and recycled or discarded. However, the bodies of most of the more than 100 climbers who died on the upper slopes of Everest have not been removed, as their weight makes carrying them down extremely difficult. (Te.N./S.V.)

History of exploration

MOUNTAINEERING ON EVEREST

The human challenge. Mount Everest is difficult to get to and more difficult to climb, even with the great advances made in equipment, transportation, communications, and weather forecasting since the first major expeditions in the 1920s. The mountain itself lies in a highly isolated location. There are no roads in the region on the Nepalese side, and before the 1960s all goods and supplies had to be carried long distances by humans and pack animals. Since then, airstrips built in the Khumbu valley have greatly facilitated transport to the Everest vicinity, although the higher areas have remained accessible only via footpaths. In Tibet there is now a road to the north-side Base Camp.

Climbing periods

There are only two brief time periods when the weather on Everest is the most hospitable for an ascent. The best one is in April and May, right before the monsoon. Once the monsoon comes, the snow is too soft and the likelihood of avalanche too great. For a few weeks in September, after the monsoon, weather conditions may also permit an attempt; by October, however, the winter storms begin and persist until March, making climbing then nearly impossible.

In addition to the challenges posed by Everest's location



Bottleneck of climbers waiting to scale the Hillary Step (left centre) on May 10, 1996. More than two dozen climbers reached the summit that day, but eight died on the descent, including Scott Fischer, the photographer, when a severe storm hit.



Members of the 1921 British reconnaissance expedition to Mount Everest; George Mallory is standing in the top row, far right.



Edmund Hillary (left) and Tenzing Norgay preparing to leave the South Col to establish the ridge camp (Camp IX) below the South Summit of Mount Everest, May 28, 1953; the two made their summit ascent the following day.



Luther G. Jerstad, member of the 1963 U.S. expedition to Mount Everest, approaching the summit on May 22; the U.S. flag there was placed on May 1 by James W. Whittaker, the first American to scale the mountain.

Plate 1: (Top left) © Scott Fischer/Woodfin Camp and Associates; (top right) © Royal Geographical Society; (bottom left) © Royal Geographical Society; photograph, Alfred Gregory; (bottom right) Barry C. Bishop/National Geographic Images Collection



American Robert Anderson, leader of the 1988 Everest expedition, following a fixed rope up a steep section of the East Face.



Porters carrying supplies up from Namche Bazar, the usual starting point for most Everest expeditions in Nepal, 1998.



Base Camp for the 1988 ascent of Mount Everest via the East Face; prayer flags extend to the left from the kitchen tent.



Trash dump near Base Camp on Khumbu Glacier, Nepal, 1998.

Plate 2: (Top left, bottom left) © Stephen Venables, (top right, bottom right) Galen Rowell/Mountain Light

and climate, the effects of high altitudes on the human body are extreme: the region in the Himalayas above about 25,000 feet is known as the "death zone." Climbers at such high altitude have much more rapid breathing and pulse rates (as their bodies try to obtain more oxygen). In addition, they are not able to digest food well (and often find eating unappealing), they sleep poorly, and they often find their thinking to be confused. These symptoms are manifestations of oxygen deprivation (hypoxia) in the body tissues, which makes any effort difficult and can lead to poor decisions being made in an already dangerous environment. Supplemental (bottled) oxygen breathed through a mask can partially alleviate the effects of hypoxia, but it can present an additional problem if a climber becomes used to the oxygen and then runs out while still at high altitude. (See also ALTITUDE SICKNESS in the *Micropædia*.)

Two other medical conditions can affect climbers at high elevations. High-altitude cerebral edema (HACE) occurs when the body responds to the lack of oxygen by increasing blood flow to the brain; the brain begins to swell, and coma and death may occur. High-altitude pulmonary edema (HAPE) is a similar condition in which the body circulates additional blood to the lungs; this blood begins to leak into the air sacs, and death is caused essentially by drowning. The most effective treatment for both conditions is to move the affected person to a lower elevation. It has been found that the drug dexamethasone is a useful emergency first-aid treatment when injected into stricken climbers, allowing them to regain movement (when they might otherwise be incapacitated) and thus descend.

Routes and techniques. The southern route via the Khumbu Icefall and the South Col is the one most commonly taken by climbers attempting to summit Everest. It is the route used by the 1953 British expedition when New Zealander Edmund (later Sir Edmund) Hillary and Sherpa Tenzing Norgay became the first men known to have reached Everest's summit. The northern route, attempted unsuccessfully by seven British expeditions in the 1920s and '30s, is also climbed. It is now generally accepted that the first successful ascent via that approach was made by a Chinese expedition in 1960, with Wang Fuzhou, Qu Yinhua, Liu Lianman, and a Tibetan, Konbu, reaching the summit. The East Face, Everest's biggest, is rarely climbed. An American team made the first ascent of it in 1983, and Carlos Buhler, Kim Momb, and Lou Reichardt reached the summit.

"Siege" climbing

Perhaps because most of the early climbers on Everest had military backgrounds, the traditional method of ascending it has been called "siege" climbing. With this technique, a large team of climbers establishes a series of tented camps farther and farther up the mountain's side. For instance, on the most frequently climbed southern route, the Base Camp on the Khumbu Glacier is at an elevation of about 17,600 feet. The theory is that the climbers ascend higher and higher to establish camps farther up the route, then come down to sleep at night at the camp below the one being established. (Mountain climbers express this in the phrase, "Climb high, sleep low.") This practice allows climbers to acclimatize to the high altitude. Camps are established along the route about every 1,500 feet of vertical elevation and are given designations of Camp I, Camp II, and so on. Finally, a last camp is set up close enough to the summit (usually about 3,000 feet below) to allow a small group (called the "assault" team) to reach the peak. This was the way the British organized their expeditions; most of the large commercial expeditions continue to use it—except that all paying clients are now given a chance at the summit. Essential to the siege climbing style is the logistical support given to the climbers by the Sherpas.

There had been a feeling among some early 20th-century climbers that ascending with oxygen, support from Sherpas, and a large party was "unsporting" or that it missed the point of mountain climbing. British explorer Eric Shipton expressed the view that these large expeditions caused climbers to lose their sense of the aesthetic of mountain climbing and to focus instead on only achieving the summit. Top mountaineers, disenchanted with the ponderous and predictable nature of these siege climbs, began in the 1970s to bring a more traditional "Alpine" style of climbing to the world's highest peaks; by the 1980s this included even Everest. In this approach, a small party of perhaps three or four climbers goes up and down the mountain as quickly as possible, carrying all needed gear and provisions. This lightweight approach precludes fixing miles of safety ropes and carrying heavy supplemental oxygen. Speed is of the essence. However, at least four weeks still must be spent at and around Base Camp acclimatizing to altitude before the party can consider a summit attempt.

(S.V.)

EARLY EXPEDITIONS

Reconnaissance of 1921. In the 1890s British army officers Sir Francis Younghusband and Charles (C.G.) Bruce, who were stationed in India, met and began discussing the possibility of an expedition to Everest. The officers became involved with two British exploring organizations—the Royal Geographical Society (RGS) and the Alpine Club—and these groups became instrumental in fostering interest in exploring the mountain. Bruce and Younghusband sought permission to mount an Everest expedition beginning in the early 1900s, but political tensions and bureaucratic difficulties made it impossible. Though Tibet was closed to Westerners, British officer John (J.B.L.) Noel disguised himself and entered it in 1913; he eventually got within 40 miles of Everest and was able to see the summit. His lecture to the RGS in 1919 once again generated interest in Everest, permission to explore it was requested of Tibet, and this was granted in 1920. In 1921 the RGS and the Alpine Club formed the Mount Everest Committee, chaired by Younghusband, to organize and finance the expedition. A party under Lieutenant Colonel C.K. Howard-Bury set out to explore the whole Himalayan range and find a route up Everest. The other members were G.H. Bullock, A.M. Kellas, George Mallory, H. Raeburn, A.F.R. Wollaston, Majors H.T. Morshead and O.E. Wheeler (surveyors), and A.M. Heron (geologist).

Noel's 1913 approach

During the summer of 1921 the northern approaches to the mountain were thoroughly explored. On the approach to Everest, Kellas died of heart failure. Because Raeburn also fell ill, the high exploration devolved almost entirely upon Mallory and Bullock. Neither had Himalayan experience, and they were faced with the problem of acclimatization besides the difficulty of the terrain.

The first object was to explore the Rongbuk valley. The party ascended the Central Rongbuk Glacier, missing the narrower opening of the eastern branch and the possible line up Everest. They returned eastward for a rest at Kharta Shekar. From there they discovered a pass at 22,000 feet, the Lhakpa (Lhagba), leading to the head of the East Rongbuk Glacier. The saddle north of Everest, despite its forbidding appearance, was climbed on September 24 by Mallory, Bullock, and Wheeler and named the North Col. A bitter wind prevented them from going higher, but Mallory had from there traced a potential route to the summit.

Attempt of 1922. Members of the expedition were Brigadier General C.G. Bruce (leader), Captain J.G. Bruce, C.G. Crawford, G.I. Finch, T.G. Longstaff, Mallory, Captain C.J. Morris, Major Morshead, Edward Norton, T.H. Somervell, Colonel E.I. Strutt, A.W. Wakefield, and Noel. It was decided that the mountain must be attempted before the onset of the summer monsoon. In the spring, therefore, the baggage was carried by Sherpas across the high, windy Plateau of Tibet.

Supplies were carried from Base Camp at 16,500 feet to an advanced base at Camp III. From there, on May 13, a camp was established on the North Col. With great difficulty a higher camp was set at 25,000 feet on the sheltered side of the North Ridge. On the next morning, May 21, Mallory, Norton, and Somervell left Morshead, who was suffering from frostbite, and pushed on through trying windy conditions to 27,000 feet near the crest of the Northeast Ridge. On May 25 Finch and Captain Bruce set out from Camp III using oxygen. Finch, a protagonist of oxygen, was justified by the results. The party, with the Gurkha Tejbir Bura, established Camp V at 25,500 feet. There they were stormbound for a day and two nights, but the next morning Finch and Bruce reached 27,300 feet and returned the same day to Camp III. A third attempt dur-

ing the early monsoon snow ended in disaster. On June 7 Mallory, Crawford, and Somervell, with 14 Sherpas, were crossing the North Col slopes. Nine Sherpas were swept by an avalanche over an ice cliff, and seven were killed. Mallory's party was carried down 150 feet but not injured.

Attempt of 1924. Members of the expedition were Brigadier General Bruce (leader), Bentley Beetham, Captain Bruce, J. de V. Hazard, Major R.W.G. Hingston, Andrew Irvine, Mallory, Norton, N.E. Odell, E.O. Shebbeare (transport), Somervell, and Noel (photographer). Noel devised a novel publicity scheme for financing this trip by buying all film and lecture rights for the expedition, which covered the entire cost of the venture. To generate interest in the climb, he designed a commemorative postcard and stamp; sacks of postcards were then mailed from Base Camp, mostly to schoolchildren who had requested them. This was the first of many Everest public relations ventures.

On the climb itself, because of wintry conditions, Camp IV on the North Col was established only on May 22 by a new and steeper though safer route; the party was then forced to descend. General Bruce had to return because of illness, and under Norton Camp IV was reestablished on June 1. At 25,000 feet, Mallory and Captain Bruce were stopped when the Sherpas became exhausted. On June 4 Norton and Somervell, with three Sherpas, pitched Camp VI at 26,800 feet; the next day they reached 28,000 feet. Norton went on to 28,100 feet, a documented height unsurpassed until 1953. Mallory and Irvine, using oxygen, set out from the North Col on June 6. On June 8 they started for the summit. Odell, who had come up that morning, believed he saw them in early afternoon high up between the mists.

Mallory and Irvine

Initially, Odell claimed to have seen them at the Third Step, though later he was less certain exactly where it had been. On the Northeast Ridge there are three "steps"—steep rock barriers—between the elevations of 27,890 and 28,870 feet that make the final approach to the summit difficult. The First Step is a limestone vertical barrier about 110 feet high. Above that is a ledge and the Second Step, which is about 160 feet high. (In 1975 a Chinese expedition from the north affixed an aluminum ladder to the step that makes climbing it much easier.) The Third Step contains another sheer section of rock about 100 feet high that leads to a more gradual slope to the summit. If Odell actually saw Mallory and Irvine at the Third Step at about 12:50 PM, then they would have been some 500 feet below the summit at that point; however, there has long been great uncertainty about all this, especially whether they made it to the top that day. The next morning Odell went up to search and reached Camp VI on June 10, but he found no trace of either man.

When Mallory was asked why he wanted to climb Everest, he replied with the famous line, "Because it's there." The British public had come to admire the determined climber over the course of his three expeditions, and they were shocked by his disappearance. (The fate of Mallory remained a mystery for 75 years; see below *Finding Mallory and commemorating the 1953 ascent.*)

Attempt of 1933. Members of the expedition were Hugh Ruttledge (leader), Captain E. St. J. Birnie, Lieutenant Colonel H. Boustead, T.A. Brocklebank, Crawford, C.R. Greene, Percy Wyn-Harris, J.L. Longland, W.W. McLean, Shebbeare (transport), Eric Shipton, Francis S. Smythe, Lawrence R. Wager, G. Wood-Johnson, and Lieutenants W.R. Smyth-Windham and E.C. Thompson (wireless).

High winds made it extremely difficult to establish Base Camp in the North Col, but it was finally done on May 1. Its occupants were cut off from the others for several days. On May 22, however, Camp V was placed at 25,700 feet; again storms set in, retreat was ordered, and V was not reoccupied until the 28th. On the 29th Wyn-Harris, Wager, and Longland pitched Camp VI at 27,400 feet. On the way down, Longland's party, caught in a blizzard, had great difficulty.

On May 30, while Smythe and Shipton came up to Camp V, Wyn-Harris and Wager set off from Camp VI. A short distance below the crest of the Northeast Ridge, they found Irvine's ice ax. They reckoned that the Second Step was impossible to ascend and were compelled to follow Norton's 1924 traverse to the Great Couloir splitting the face below the summit. They crossed the gorge to a height about the same as Norton's but then had to return. Smythe and Shipton made a final attempt on June 1. Shipton returned to Camp V. Smythe pushed on alone, crossed the couloir, and reached the same height as Wyn-Harris and Wager. On his return the monsoon ended operations.

Also in 1933 a series of airplane flights were conducted over Everest, which permitted the summit and surrounding landscape to be photographed. In 1934 Maurice Wilson, an inexperienced climber who was obsessed with the mountain, died above Camp III attempting to climb Everest alone.

Wilson's 1934 climb

Reconnaissance of 1935. In 1935 an expedition led by Shipton was sent to reconnoitre the mountain, explore the western approaches, and discover more about monsoon conditions. Other members were L.V. Bryant, E.G.H. Kempson, M. Spender (surveyor), H.W. Tilman, C. Warren, and E.H.L. Wigram. In late July the party succeeded in putting a camp on the North Col, but dangerous avalanche conditions kept them off the mountain. One more visit was paid to the North Col area in an attempt on Changtse (the north peak). During the reconnaissance Wilson's body was found and buried; his diary was also recovered.

Attempts of 1936 and 1938. Members of the 1936 expedition were Ruttledge (leader), J.M.L. Gavin, Wyn-Harris, G.N. Humphreys, Kempson, Morris (transport), P.R. Oliver, Shipton, Smyth-Windham (wireless), Smythe, Warren, and Wigram. This expedition had the misfortune of an unusually early monsoon. The route up to the North Col was finished on May 13, but the wind had dropped, and heavy snowfalls almost immediately after the camp was established put an end to climbing the upper part of the mountain. Several later attempts to regain the col failed.

Members of the 1938 expedition were Tilman (leader), P. Lloyd, Odell, Oliver, Shipton, Smythe, and Warren. Unlike the two previous parties, some members of this expedition used oxygen. The party arrived early, in view of the experience of 1936, but they were actually too early and had to withdraw, meeting again at Camp III on May 20. The North Col camp was pitched under snowy conditions on May 24. Shortly after, because of dangerous snow, the route was changed and a new one made up the west side of the col. On June 6 Camp V was established. On June 8, in deep snow, Shipton and Smythe with seven Sherpas pitched Camp VI, at 27,200 feet, but the next day they were stopped above it by deep powder. The same fate befell Tilman and Lloyd, who made their attempt on the 11th. Lloyd benefited from an open-circuit oxygen apparatus that partly allowed him to breathe the outside air. Bad weather compelled a final retreat.

GOLDEN AGE OF EVEREST CLIMBS

Reconnaissance of 1951. After 1938, expeditions to Everest were interrupted by World War II and the immediate postwar years. In addition, the Chinese takeover of Tibet in 1950 precluded using the northern approach. In 1951 permission was received from the Nepalese for a reconnaissance of the mountain from the south. Members of the expedition were Shipton (leader), T.D. Bourdillon, Edmund Hillary, W.H. Murray, H.E. Riddiford, and M.P. Ward. The party marched through the monsoon, reaching Namche Bazar, the chief village of Solu-Khumbu, on September 22. At Khumbu Glacier they found it possible to scale the great icefall seen by Mallory from the west. They were stopped at the top by a huge crevasse but traced a possible line up the Western Cwm (cirque, or valley) to the South Col, the high saddle between Lhotse and Everest.

Approach from Nepal

Spring attempt of 1952. Expedition members were E. Wyss Dunant (leader), J.J. Asper, R. Aubert, G. Chevalley, R. Dittert (leader of climbing party), L. Flory, E. Hofstetter, P.C. Bonnant, R. Lambert, A. Roch, A. Lombard (geologist), and A. Zimmermann (botanist). This strong Swiss party first set foot on the Khumbu Icefall on April 26. After considerable difficulty with the route, they overcame the final crevasse by means of a rope bridge. The 4,000-

foot face of Lhotse, which had to be climbed to reach the South Col, was attempted by a route running beside a long spur of rock christened the Éperon des Genevois. The first party, Lambert, Flory, Aubert, and Tenzing Norgay (sirdar, or leader of the porters), with five Sherpas, tried to reach the col in one day. They were compelled to bivouac quite a distance below it (May 25) and the next day reached the summit of the Éperon, at 26,300 feet, whence they descended to the col and pitched camp. On May 27 the party (less the five Sherpas) climbed up the Southeast Ridge. They reached approximately 27,200 feet, and there Lambert and Tenzing bivouacked. The next day they pushed on up the ridge and turned back at approximately 28,000 feet. Also on May 28 Asper, Chevalley, Dittert, Hofstetter, and Roch reached the South Col, but they were prevented by wind conditions from going higher and descended to the base.

Autumn attempt of 1952. Members of this second Swiss expedition were Chevalley (leader), J. Buzio, G. Gross, Lambert, E. Reiss, A. Spöhel, and Norman Dyhrenfurth (photographer). The party found the icefall easier to climb than in the spring and had brought poles to bridge the great crevasse. Camp IV was occupied on October 20. Higher up, however, they were constantly harassed by bitterly cold winds. On the ice slope below the Éperon one Sherpa was killed, and the party took to the glaciated face of Lhotse on the right. The South Col was reached on November 19, but the summit party climbed only 300 feet higher before being forced to withdraw.

The historic ascent of 1953. Members of the expedition, which was sponsored by the Royal Geographical Society and the Alpine Club, were Colonel John Hunt (leader; later Baron Hunt), G.C. Band, Bourdillon, R.C. Evans, A. Gregory, Edmund Hillary, W.G. Lowe, C.W.F. Noyce, M.P. Ward, M.H. Westmacott, Major C.G. Wylie (transport), T. Stobart (cinematographer), and L.G.C. Pugh (physiologist). After three weeks' training on neighbouring mountains, a route was worked out up the Khumbu Icefall, and it was possible to start ferrying loads of supplies to the Western Cwm head. Two forms of oxygen apparatus, closed- and open-circuit types, were tried. As a result of a reconnaissance of Lhotse in early May, Hunt decided that Bourdillon and Evans, experts on closed-circuit, should make the first attempt from the South Col. Hillary with Tenzing Norgay as sirdar were to follow, using open-circuit and a higher camp.

Preparations

Lowe spent nine days, most of them with the Sherpa Ang Nyima, working at the lower section of the Lhotse face. On May 17 a camp was pitched on it at 24,000 feet. The route on the upper part of the face, over the top of the Éperon, was first made by Noyce and the Sherpa Annullu on May 21. The next day 13 Sherpas led by Wylie, with Hillary and Tenzing ahead, reached the col and dumped loads. The fine weather continued from May 14 but with high winds. On May 24 the first summit party, with Hunt and two Sherpas in support, reached the col. On the 26th Evans and Bourdillon climbed to the South Summit of Everest, but by then it was too late in the day to go farther. Meanwhile Hunt and the Sherpa Da Namgyal left loads for a ridge camp at 27,350 feet.

On the 28th the ridge camp was established at 27,900 feet by Hillary, Tenzing, Lowe, Gregory, and Ang Nyima, and Hillary and Tenzing passed the night there. The two set out early on the morning of May 29, reaching the South Summit by 9:00 AM. The first challenge on the final approach to the summit of Everest was a fairly level ridge of rock some 400 feet long flanked by an ice "cornice"; to the right was the East (Kangshung) Face, and to the left was the Southwest Face, both sheer drop-offs. The final obstacle, about halfway between the South Summit and the summit of Everest, was a steep spur of rock and ice—now called the Hillary Step. Though it is only about 55 feet high, the formation is difficult to climb because of its extreme pitch and because a mistake would be deadly. Climbers now use fixed ropes to ascend this section, but Hillary and Tenzing had only ice-climbing equipment. First Hillary and then Tenzing tackled the barrier much as one would climb a rock chimney (a crack or gorge large enough to permit a climber to enter)—*i.e.*, they inched up a little at a time with their backs against the rock wall and their feet wedged in a crack between the rock and ice.

At the summit

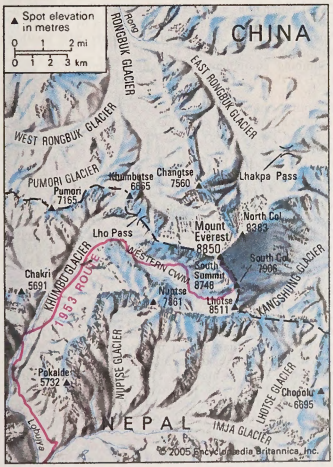
They reached the summit of Everest at 11:30 AM. Hillary turned to Tenzing, and the men shook hands; Tenzing then embraced Hillary in a hug. Hillary took photos, and the two searched for but did not find signs that Mallory and Irvine had been to the summit. Tenzing, a Buddhist, made an offering of food for the mountain; Hillary left a crucifix Hunt had given him. The two men ate some sweets and then headed down. They had spent about 15 minutes on the top of the world.

They were met on the slopes above the South Col that afternoon by Lowe and Noyce. Hillary is reputed to have said to Lowe, "Well, George, we knocked the bastard off." By June 2 the whole expedition had reassembled at the Base Camp.

A correspondent for *The Times*, James (later Jan) Morris, had hiked up to Camp IV to follow the story more closely and was on hand to cover the event. Worried that other papers might scoop him, Morris wired his story to the paper in code. It reached London in time to appear in the June 2 edition. A headline from another London paper published later that day, "All this, and Everest too!" referred to the fact that Elizabeth II was being crowned on the same day on which the news broke about the success on Everest. After years of privation during and after World War II and the subsequent loss of empire, the effect of the successful Everest ascent was a sensation for the British public. The feat was also celebrated worldwide, but nowhere like in Britain and the Commonwealth, whose climbers had been so closely associated with Everest for more than 30 years. As Walt Unsworth described it in *Everest*,

> And so, the British, as usual, had not only won the last battle but had timed victory in a masterly fashion. Even had it not been announced on Coronation Day it would have made world headlines, but in Britain the linking of the two events was regarded as almost an omen, ordained by the Almighty as a special blessing for the dawn of a New Elizabethan Age. It is doubtful whether any single adventure had ever before received such universal acclaim: Scott's epic last journey, perhaps, or Stanley's finding of Livingstone—it was of that order.

The expedition little expected the fanfare that awaited them on their return to Britain. Both Hillary and Hunt



Route of Edmund Hillary and Tenzing Norgay to the summit of Mount Everest, May 1953.

were knighted in July (Hunt was later made a life peer), and Tenzing was awarded the George Medal. All members of the expedition were feted at parties and banquets for months, but the spotlight fell mostly on Hillary and Tenzing as the men responsible for one of the defining events of the 20th century.

Everest-Lhotse, 1956. In 1956 the Swiss performed the remarkable feat of getting two ropes up Everest and one up Lhotse, using oxygen. Members of the expedition were A. Eggler (leader), W. Diehl, H. Grimm, H.R. von Gunten, E. Leuthold, F. Luchsinger, J. Marmet, F. Müller, Reiss, A. Reist, and E. Schmied. They followed roughly the British route up the icefall and the Lhotse face. From their Camp VI Reiss and Luchsinger reached the summit of Lhotse on May 18. Camp VI was moved to the South Col, and the summit of Everest was reached from a camp at 27,500 feet by Marmet and Schmied (May 23) and Gunten and Reist (May 24).

Attempts of 1960. In 1960 an Indian expedition with Sherpas, led by Brigadier Gyan Singh, attempted to scale Everest from the south. Camp IV was established in the Western Cwm on April 19. Bad weather followed, but a party using oxygen reached the South Col on May 9. On May 24 three members pitched a tent at 27,000 feet on the Southeast Ridge but were turned back by wind and weather at about 28,300 feet. Continued bad weather prevented the second summit party's leaving the South Col.

Chinese expedition

Also that spring it was reported that a Chinese expedition led by Shi Zhanzhun climbed Everest from the north. By their account they reached the North Col in April, and on May 24 Wang Fuzhou, Qu Yinhua, Liu Lianman, and a Tibetan mountaineer, Konbu, climbed the slab by a human ladder, reaching the top at 4:20 AM to place the Chinese flag and a bust of Mao Zedong. The credibility of their account was doubted at the time but later was generally accepted (see below *The north approach*).

(C.W.F.N./H.C.J.H./S.V.)

The U.S. ascent of 1963. The first American expedition to Everest was led by the Swiss climber Norman Dyhrenfurth, who selected a team of 19 mountaineers and scientists from throughout the United States and 37 Sherpas. The purpose was twofold: to reach the summit and to carry out scientific research programs in physiology, psychology, glaciology, and meteorology. Of particular interest were the studies on how the climbers changed physiologically and psychologically under extreme stresses at high altitudes where oxygen deprivation was unavoidable. These studies were related to the U.S. space program, and among the 400 sponsors of the expedition were the National Geographic Society, the U.S. State Department, the National Science Foundation, the Office of Naval Research, the National Aeronautics and Space Administration, the U.S. Army Quartermaster Corps, the Atomic Energy Commission, and the U.S. Air Force.

On February 20 the expedition left Kathmandu, Nepal, for Everest, 180 miles away. More than 900 porters carried some 26 tons of food, clothing, equipment, and scientific instruments. Base Camp was established at 17,800 feet on Khumbu Glacier on March 20, one month earlier than on any previous expedition. For the next five weeks the team selected a route toward the summit and established and stocked a series of camps up the mountain via the traditional South Col route. They also explored the more difficult and untried West Ridge route. On May 1 James W. Whittaker and the Sherpa Nawang Gombu, nephew of Tenzing Norgay, reached the summit despite high winds. On May 22 four other Americans reached the top. Two of them, William F. Unsoeld and Thomas F. Hornbein, made mountaineering history by ascending the West Ridge, which until then had been considered unclimbable. They descended the traditional way, along the Southeast Ridge toward the South Col, thus also accomplishing the first major mountain traverse in the Himalayas. On the descent, Unsoeld and Hornbein, along with Barry C. Bishop and Luther G. Jerstad (who had also reached the summit that day via the South Col), were forced to bivouac in the open at 28,000 feet. All suffered frostbite, and Bishop and Unsoeld later lost their toes; the two had to be carried out of Base Camp on the backs of Sherpas. On July 8 Dyhrenfurth and all members of the expedition were presented the National Geographic Society's Hubbard Medal by President John F. Kennedy.

The Indian ascent of 1965. In 1965 a 21-man Indian expedition, led by Lieutenant Commander M.S. Kohli, succeeded in putting nine men on the summit of Everest. India thus became the fourth country to scale the world's highest mountain. One of the group, Nawang Gombu, became the first person ever to climb Mount Everest twice, having first accomplished the feat on the U.S. expedition.

(B.C.B.)

DEVELOPMENTS SINCE 1965

The 1970s. *The Southwest Face.* From 1966 to 1969 the government of Nepal banned mountaineers from climbing in the Nepalese Himalayas. When the ranges were reopened in 1969, the world's top mountaineers—following the American example of 1963—set their eyes on new routes to Everest's summit. With Tibet still closed and only the southern approach available, the obvious challenge was the huge Southwest Face rising from the Western Cwm. The crux of the problem was the Rock Band—a vertical cliff 2,000 feet high starting at about 26,250 feet. A Japanese reconnaissance expedition reached the foot of the Rock Band in the autumn of 1969 and returned in spring 1970 for a full-scale attempt led by Matsukata Saburō. Failing to make further progress on the Southwest Face, the expedition switched to the easier South Col route, getting the first Japanese climbers, including the renowned Japanese explorer Uemura Naomi, to the summit.

New summit routes

Expeditions continued to lay "siege" to the Southwest Face. The most publicized of these climbs was the 1971 International Expedition led by Norman Dyhrenfurth; however, internationalist ideals were savaged by the stresses of high altitude, and the expedition degenerated into rancour between the British and non-British climbers. In the spring of 1972 a European expedition led by the German Karl Herrligkoffer was equally inharmonious.

The battle for the Southwest Face continued in a predictable pattern: large teams, supported by Sherpas acting as high-altitude porters, established a succession of camps in the broad, snow-covered couloir leading to the foot of the intractable Rock Band. Success finally came in the autumn of 1975 to a British expedition led by Chris (later Sir Chris) Bonington, who got the full team and its meticulously prepared equipment to Base Camp by the end of August and made the most of the mainly calm weather during the September time window.

Climbing equipment had changed significantly since 1953. In the mid-1970s rigid box-shaped tents were bolted to aluminum alloy platforms dug into the 45° slope. Smooth-sheathed nylon ropes were affixed to the rock face to make a continuous safety line, which climbers could ascend and descend very efficiently. The 1975 expedition was a smooth operation that utilized a team of 33 Sherpas and was directed by some of the world's best mountaineers. Unlike previous expeditions, this team explored a deep gully cutting through the left side of the Rock Band, with Paul Braithwaite and Nick Estcourt breaking through to establish Camp VI at about 27,000 feet. From there Doug Scott and Dougal Haston made a long, bold traverse rightward, eventually gaining the South Summit and continuing over the Hillary Step to the Everest summit, which they reached at 6:00 PM. Rather than risk descending in the dark, they bivouacked in a snow cave close to the South Summit—at 28,750 feet, this was the highest bivouac in climbing history until the Sherpa Babu Chiri bivouacked on the summit itself in 1999. Their oxygen tanks were empty, and they had neither tent nor sleeping bags, but both men survived the ordeal unharmed and returned safely to Camp VI in the morning. Two days later Peter Boardman and the Sherpa Pertemba reached the summit, followed by Mick Burke heading for the top in deteriorating weather. Burke never returned; he is presumed to have fallen to his death in the whiteout conditions.

The first ascent by a woman. When Scott and Haston reached the summit of Everest in September 1975, they found a metal surveying tripod left the previous spring by a Chinese team—definitive proof of the first uncontested

First woman to summit

ascent from the north. The Chinese team included a Tibetan woman, Phantog, who reached the summit on May 27. The honours for the first woman to summit Everest, however, belong to the Japanese climber Tabei Junko, who reached the top from the South Col on May 16. She was climbing with the first all-women expedition to Everest (although male Sherpas supported the climb.)

The West Ridge direct ascent. With the Southwest Face climbed, the next obvious—and harder—challenge was the complete West Ridge direct ascent from Lho Pass (Lho La). Just getting to Lho Pass from Base Camp is a major climb. The West Ridge itself then rises 9,200 feet over a distance of 3.5 miles, much of it over difficult rock. In 1979 a Yugoslav team, led by Tone Skarja, made the first ascent, fixing ropes to Camp V at an elevation of about 26,750 feet, with one rope fixed farther up a steep rock chimney. On May 13 Andrej Stremfelj and Jernej Zaplotnik set out from Camp V for the summit. Above the chimney there were two more hard pitches of rock climbing. With no spare rope to fix in place, the climbers realized that they would not be able to descend via these difficult sections. After reaching the summit in midafternoon, they descended by the Hornbein Couloir, bypassing the hardest part of the West Ridge to regain the safety of Camp IV late that evening.

Climbing without supplemental oxygen. Beginning in the 1920s and '30s, the received wisdom had been that an Everest climb needed a team of at least 10 climbers supported by Sherpas and equipped with supplemental oxygen for the final stages. In 1978 that belief was shattered by the Italian (Tyrolean) climber Reinhold Messner and his Austrian climbing partner Peter Habeler. They had already demonstrated on other high Himalayan peaks the art of Alpine-style climbing—moving rapidly, carrying only the barest essentials, and sometimes not even roping together for safety—as opposed to the standard siege style. Another innovation was their use of plastic boots, which were much lighter than the leather equivalent. In 1978 Messner and Habeler attached themselves as a semiautonomous unit to a large German-Austrian expedition led by Oswald Ölz. At 5:30 AM on May 8, the two men left their tent at the South Col and started up the summit ridge carrying nothing but ice axes, cameras, and a short rope. The only external assistance was from the Austrians at their top camp, above the South Col, where the two stopped briefly to melt snow for drinking water. (In those days it was still common practice to place a top camp higher than the South Col; nowadays virtually all parties start their final push from the col, some 3,100 feet below the summit.) Maintaining a steady ascent rate of about 325 feet per hour, they reached the summit at 1:15 PM. Habeler was terrified of possibly suffering brain damage from the lack of oxygen and made a remarkable descent to the South Col in just one hour. Messner returned later that afternoon. Exhausted—and in Messner's case snow-blind from having removed his goggles—the two were escorted back down to the Western Cwm the next morning by the Welsh climber Eric Jones.

Messner and Habeler had proved that human beings could climb to the top of the world without supplemental oxygen; the German Hans Engl and the Sherpas Ang Dorje and Ang Kami were among several climbers who duplicated this feat in the autumn of 1978. However, for Messner, climbing Everest without supplemental oxygen was not enough: he now wanted to reach the summit completely alone. To do that unroped over the treacherous crevasses of the Western Cwm was considered unthinkable, but it was possible on the less-crevassed northern approach through Tibet; by the late 1970s Tibet was again becoming an option.

First ascents from Tibet

The north approach. After China occupied Tibet in 1950, permission was denied to any expeditions from noncommunist countries wishing to climb Everest. In 1960 the Chinese army built a road to the Rongbuk Base Camp, then claimed to have made the first ascent of Everest from the north, following the North Col–North Ridge–Northeast Ridge route earlier explored by prewar British expeditions. Many in the West doubted the Chinese assertion, mainly because the official account—which included the claim that Qu Yinhua had scaled the notorious vertical cliff of the Second Step barefoot and which also made constant references to party solidarity and the inspiration of Chairman Mao—was deemed so improbable. Not for the last time, Everest was used as a vehicle for propaganda.

Since that time, however, people in the West have seen Qu's feet, mutilated by frostbite, and experts have reexamined the 1960 photos and film—many now believe that Qu, Wang Fuzhou, Liu Lianman, and the Tibetan, Konbu, did indeed reach the summit on May 25, 1960. What none can doubt is the Chinese repeat ascent of 1975 by eight Tibetans (including Phantog) and one Chinese. On that climb the group bolted an aluminium ladder to the Second Step, which has remained there and greatly aided all subsequent ascents on what has become the standard route from the north.

The 1980s. In 1979 the Chinese authorities announced that noncommunist countries could again begin mounting Everest expeditions through Tibet. Japan was first to do so, with a joint Sino-Japanese expedition led by Watanabe Hyōrikō in the spring of 1980. Half of the 1980 team repeated the Chinese North Ridge–Northeast Ridge route, with Katō Yasuo reaching the summit alone—making him the first person to climb Everest from the south and north. Meanwhile, another team made the first complete ascent of the North Face from the Central Rongbuk Glacier. The upper face is split by the Great Couloir on the left and the Hornbein Couloir (first attained from the West Ridge in 1963) on the right. The 1980 team climbed a lower couloir (the Japanese Couloir) that led directly to the base of the Hornbein Couloir, which was then followed to the top. Shigehiro Tsuneo and Ozaki Takashi ran out of oxygen about four hours below the summit but continued without it, reaching the summit late and bivouacking on the way down. Once again, modern insulated clothing and modern psychological attitudes about what was possible on Everest had allowed climbers to push on in a manner unthinkable to the prewar pioneers.

First solo climb. Reinhold Messner arrived at Rongbuk during the monsoon in July 1980. He spent a month acclimatizing, did one reconnaissance to the North Col to cache supplies there, then set off alone from Advance Base on the East Rongbuk Glacier before dawn on August 18. After a lucky escape from a concealed crevasse into which he had fallen, he reached the North Col, collected his gear, and continued to climb higher up the North Ridge. He then slanted diagonally right, as George Finch and Geoffrey Bruce had done in 1922, traversing a full 1.2 miles before stopping to pitch his tent a second time, at 26,900 feet. On the third day he entered the Great Couloir, continued up it, and achieved what had eluded Edward Norton, Lawrence Wager, Percy Wyn-Harris, and Francis Smythe by climbing rightward out of the couloir, onto the final terraces, and to the summit. Messner later recounted,

Messner's account

> I was in continual agony; I have never in my whole life been so tired as on the summit of Everest that day. I just sat and sat there, oblivious to everything. . . . I knew I was physically at the end of my tether.

Back at his tent that night he was too weak even to eat or drink, and the next morning he jettisoned all his survival equipment, committing himself to descending all the way to Advance Base Camp in a single day.

Further exploration from Tibet. Messner's 1980 solo climb demonstrated just what could be done on the world's highest mountain. With that same bold spirit, a four-man British team came to Rongbuk in 1982 to attempt the complete Northeast Ridge from Raphu Pass (Raphu La). While he was leading the climb of the first of the three prominent Pinnacles that start at about 26,900 feet, Dick Renshaw suffered a mild stroke and was invalided home. The expedition leader, Chris Bonington, felt too tired to go back up, and thus it was left to Peter Boardman and Joe Tasker to attempt the final ascent. They were last seen alive between the First Pinnacle and the Second Pinnacle on May 17. Boardman's body was found 10 years later, sitting in the snow near that point; Tasker has not been found.

In 1981 a large American team made the first-ever attempt on Everest's gigantic East Face from Kangshung Glacier. Avalanche risk thwarted the attempt, but the team

returned in autumn of 1983 to attempt again the massive central buttress of the face. This produced some spectacularly hard climbing, led by George Lowe. Above the buttress, the route followed a broad spur of snow and ice to reach the Southeast Ridge just below the South Summit. Carlos Buhler, Lou Reichardt, and Kim Momb reached the Everest summit on October 8, followed the next day by Jay Cassell, Lowe, and Dan Reid.

In 1984 the first Australians to attempt Everest chose a new route up the North Face, climbing through the huge central snowfield, dubbed "White Limbo," to gain the Great Couloir. Then, like Messner in 1980, the Australians cut out right, with Tim Macartney-Snape and Greg Mortimer reaching the summit at sunset before making a difficult descent in the dark.

The most remarkable achievement of this era was the 1986 ascent by the Swiss climbers Jean Troillet and Erhard Loretan. Like Messner, they snatched a clear-weather window toward the end of the monsoon for a lightning dash up and down the mountain. Unlike Messner, they did not even carry a tent and sleeping bags. Climbing by night, resting during the comparative warmth of the day, they took just 41.5 hours to climb the Japanese and Hornbein couloirs up the North Face; then, sliding most of the way on their backsides, they descended in about 4.5 hours.

Developments in Nepal. While the most dazzling deeds were being done on the Tibetan side of Everest, there was still much activity in Nepal during the 1980s, with the boldest pioneering expeditions coming from eastern European countries. For dogged teamwork, nothing has surpassed the first winter ascent of Everest. Completed in 1980 by a team of phenomenally rugged Polish climbers, this ascent was led by Andrzej Zawada; expedition members Leszek Cichy and Krzysztof Wielicki reached the summit on February 17. To crown this success, Zawada then led a spring expedition to make the first ascent of the South Pillar (left of the South Col), getting Andrzej Czok and Jerzy Kukuczka to the summit. Kukuczka, like Messner, would eventually climb all of the world's 26,250-foot (8,000-metre) peaks, nearly all by difficult new routes.

First winter ascent

Several teams attempted to repeat the Yugoslav West Ridge direct route without success, until a Bulgarian team did so in 1984. The first Bulgarian to reach the summit, Christo Prodanov, climbed without supplemental oxygen, was forced to bivouac overnight during the descent, and died—one of four summiteers who climbed without oxygen in the 1980s and failed to return.

The first Soviet expedition to Everest, in 1982, climbed a new route up the left-hand buttress of the Southwest Face, involving harder climbing than the original 1975 route. Led by Evgeny Tamm, the expedition was highly successful, putting 11 Soviet climbers on the summit.

The end of an era. The last of the great pioneering climbs of the decade was via a new route up the left side of the East Face to the South Col. Led by American Robert Anderson, it included just four climbers who had no Sherpa support and used no supplemental oxygen. British climber Stephen Venables was the only member of this expedition to reach the summit, on May 12, 1988. After a harrowing descent, during which Venables was forced to bivouac overnight without a tent, all four members of the team made it back to the Base Camp.

During the same period, more than 250 members of the "Asian Friendship Expedition" from China, Nepal, and Japan staged a simultaneous traverse of the mountain from north and south, which was recorded live on television. Also in 1988 the Sherpas Sungdare and Ang Rita both made their fifth summit of the mountain. (By 2002 the Sherpa Apa had made a then-record 12 summits). That autumn the ace French climber, Marc Boivin, made the first paragliding descent from the summit; New Zealander Russell Brice and Briton Harry Taylor climbed the infamous Pinnacles on the Northeast Ridge; and four Czech climbers disappeared in a storm after making an Alpine-style climb of the Southwest Face without supplemental oxygen. The following year five Poles were lost in an avalanche on the West Ridge.

The increasing activity on Everest in 1988 foreshadowed what was to come. At the start of the spring season that year fewer than 200 individuals had summited Everest. However, by the 2003 season, a half century after the historic climb by Hillary and Tenzing, that number exceeded 1,200, and more than 200 climbers had summited Everest two or more times. It became increasingly common for dozens of climbers to reach the summit on a single day; on May 23, 2001, nearly 90 accomplished the feat.

Since 1990. *Commercialism and extraordinary feats.* In the 1950s and '60s the expense of mounting an expedition to Everest was so great and the number of climbers familiar with the Himalayas so few that there were many years in which no team attempted the mountain. By the 1970s expeditions had become more common, but Nepal was still issuing only two or three permits per year. In the 1980s permits became available for both the pre- and post-monsoon seasons and for routes via China as well as Nepal, and the total number of expeditions increased to about 10 per year. During the 1990s it became normal for there to be at least 10 expeditions per season on each side of the mountain. At times several expeditions would be operating simultaneously, which led to traffic jams in some of the narrower passages.

Rising number of climbers

In pure mountaineering terms, the big achievements of the decade were the first winter ascent of the Southwest Face in 1993 (by a Japanese team led by Yagihara Kuniaki), the first complete ascent of the Northeast Ridge in 1995 (by another Japanese team led by Kanzaki Tadao), and the first ascent of the North-Northeast Couloir in 1996 (by a Russian team led by Sergei Antipin).

Most of the activity, however, became concentrated on the two "normal" routes via the South Col and North Col; there the majority of expeditions were commercial operations, with clients paying for (generally) efficient logistics, satellite weather forecasts, the use of a copious amount of fixed ropes, and an increasingly savvy Sherpa workforce. One of the most successful operators, New Zealander Rob Hall, had led successful teams up the South Col route to the summit in 1990 and in 1992, '93, and '94. On May 10, 1996, his group and several other teams were caught at the summit in a bad afternoon storm. Hall and his American client, Doug Hansen, both died at the South Summit. An American guide from a separate commercial expedition, Scott Fischer, also died, along with several other climbers, including three Indians on the Northeast Ridge.

Although the deaths in the late 1980s had gone almost unnoticed, those from the 1996 storm were reported instantly over the Internet and generated massive press coverage and disaster literature. In all, 12 climbers died in that year's pre-monsoon season. The 1996 disaster may have caught the world's attention, but it did nothing to decrease the lure of Everest. If anything, commercial traffic increased dramatically, despite the obvious message that no guide can guarantee a climber's safety at such great heights.

Meanwhile, a few individuals continued to achieve astounding new feats. In 1990 Tim Macartney-Snape traveled on foot all the way from sea level in the Bay of Bengal to the summit of Everest, without supplemental oxygen. Goran Kropp took this a step further in 1996 by bicycling all the way from his native Sweden before ascending Everest; he then cycled home. In 2001 the first blind person, American Erik Weihenmayer, summited Everest; he was an experienced climber who had already scaled peaks such as Mount McKinley and Kilimanjaro before his climb of Everest. For sheer physiological prowess, however, few could match the Sherpas: in 1999 Babu Chiri climbed the southern route from Base Camp to summit in 16 hours 56 minutes, an accomplishment surpassed by two Sherpas in 2003—the second, Lakpa Gelu, took just 10 hours 56 minutes.

Some of the most remarkable of more recent "stunts" have been unusual descents. In 1996 Italian Hans Kammerlander made a one-day ascent and descent of the north side, the latter partly accomplished on skis. In 1999 Pierre Tardivel managed to ski down from the South Summit. The first complete uninterrupted ski descent from the summit was by Slovenian Davo Karničar in 2000, upstaged a year later by the French extreme sportsman Marco Siffredi with his even more challenging snowboard descent of the North Face.

Descents on skis

Finding Mallory and commemorating the 1953 ascent. Two notable Everest events bracketed the turn of the 21st century. In the spring of 1999, 75 years after George Mallory and Andrew Irvine had disappeared climbing Everest, an expedition led by American Eric Simonson set out to learn their fate. On May 1 members of the team found Mallory's body lying on a scree terrace below the Yellow Band at about 26,700 feet. It was determined that Mallory had died during or immediately after a bad fall: he had skull and compound leg fractures, and bruising was still visible on the preserved torso—probably caused by a rope that was still tied around his waist. The team could not determine if the body was the same one found by a Chinese climber in 1975 or if that one had been the body of Irvine. It was clear, however, that both Mallory and Irvine had been involved in a serious fall that broke the rope which undoubtedly joined them. Personal effects found on Mallory included his goggles, altimeter, and a pocketknife, but not the camera he had taken with him when he left for the summit. It had been hoped that the film from it (if it could be developed) might have revealed more about the climb, especially if the pair had reached the summit.

The 50th anniversary of Tenzing and Hillary's historic ascent was widely observed in 2003. Commemoration of the event actually began the previous May, when second-generation summiteers—Hillary's son and Barry Bishop's son—scaled the peak (the younger Hillary speaking to his father in New Zealand from the top via satellite phone); Tenzing's son, Jamling Norgay, also participated in the expedition but did not make the final summit climb. In the spring of 2003 scores of climbers were able to reach the top of Everest before the May 29 anniversary date. Celebrations were held in several locations worldwide on the day itself, including one in Kathmandu where hundreds of past summit climbers joined Hillary and other members of the 1953 expedition.

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Everest climbs have been well documented on film, beginning with J.B.L. Noel's film of the 1922 expedition. Films and documentaries of interest include *The Conquest of Everest* (1953), directed by TOM STOBART, of the first successful expedition; *The Race for Everest* (2003), directed by MICK CONEFREY, chronicling the buildup to the 1953 ascent; *Americans on Everest* (1963), directed by NORMAN DYHRENFURTH, on the first ascent of the West Ridge; and *Everest the Hard Way* (1975), directed by NED KELLY and CHRISTOPHER RALLING, concerning the Southwest Face expedition. Veteran climber DAVID BRESHEARS began shooting and directing films of Everest in the early 1980s, and his work includes *Ascent of Mount Everest* (1983), *The Mystery of Mallory and Irvine* (1987), *Everest: The Death Zone* (1998), and *Everest* (1998), the last shot in the IMAX wide-screen format during the spring expeditions of 1996. (S.V.)

Human Evolution

Zoologically, humans are *Homo sapiens*, a culture-bearing, upright-walking species that lives on the ground and first evolved in Africa between 100,000 and 200,000 years ago. We are now the only living members of the zoological family Hominidae, but there is abundant fossil evidence to indicate that we were preceded for millions of years by other hominids, or humanlike creatures, such as *Australopithecus*, and our species also lived for a time contemporaneously with at least one other hominid, *Homo neanderthalensis* (the Neanderthals). In addition, humans and our hominid predecessors have always shared the Earth with other hominoids, or apelike primates, from the modern-day gorilla to the long-extinct *Dryopithecus*.

Human evolution is the process by which human beings developed on Earth from now-extinct primates. That we and the other hominids are somehow related and that the hominids and the other hominoids, both living and extinct, are also somehow related is accepted by anthropologists and biologists everywhere. Yet the exact nature of our evolutionary relationships has been the subject of debate and investigation since the great British naturalist Charles Darwin published his monumental books *On the Origin of Species* (1859) and *The Descent of Man* (1871). Darwin never claimed, as some of his Victorian contemporaries insisted he had, that "man was descended from the apes," and modern scientists would view such a statement as a useless simplification—just as they would dismiss any popular notions that a certain extinct species is the "missing link" between man and the apes. There is theoretically, however, a common hominoid ancestor that existed millions of years ago. This ancestral species does not constitute a "missing link" along a lineage but rather a node for divergence into separate lineages. This ancient primate has not been identified and may never be known with certainty, because fossil relationships are unclear even within the human lineage, which is more recent. In fact, the human "family tree" may be better described as a "family bush," within which it is impossible to connect a full chronological series of species, leading to *Homo sapiens*, that experts can agree upon.

The primary resource for detailing the path of human evolution will always be fossil specimens. Certainly, the trove of fossils from Africa and Eurasia indicates that, unlike today, more than one species of our family has lived at the same time for most of human history. The nature of specific fossil specimens and species can be accurately described, as can the location where they were found and the period of time when they lived; but questions of how species lived and why they might have either died out or evolved into other species can be addressed only by formulating scenarios, albeit scientifically informed ones. These scenarios are based on contextual information gleaned from localities where the fossils were collected. In devising such scenarios and filling in the human family bush, researchers must consult a large and diverse array of fossils, and they must also employ refined excavation methods and records, geochemical dating techniques, and data from other specialized fields such as genetics, ecology and paleoecology, and ethology (animal behaviour)—in short, all the tools of the multidisciplinary science of paleoanthropology.

The first section of this article is a discussion of the broad career of the Hominidae from its probable beginnings millions of years ago in the Miocene Epoch to the development of tool-based and symbolically structured human culture only tens of thousands of years ago, during the geologically recent Pleistocene Epoch. Particular attention is paid to the fossil evidence for this history and to the principal models of evolution that have gained the most credence in the scientific community. Following this section are independent treatments of specific hominid groups. The article concludes with a section that discusses the concept of race. See EVOLUTION, THE THEORY OF, for a full explanation of evolutionary theory, including its main proponents both before and after Darwin, its arousal of both resistance and acceptance in society, and the scientific tools used to investigate the theory and prove its validity.

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EVOLUTION OF THE HUMAN FAMILY, HOMINIDAE

Background and beginnings in the Miocene

It is generally agreed that the taproot of the human family shrub—the Hominidae—is to be found among apelike species of the Middle Miocene Epoch (16.6 to 11.2 million years ago [mya]) or Late Miocene Epoch (11.2 to 5.3 mya). Genetic data based on molecular clock estimates support a Late Miocene ancestry. Various Eurasian and African Miocene primates have been advocated as possible ancestors to the early hominids, which came on the scene during the Pliocene Epoch (5.3 to 1.6 mya). Though there is no consensus among experts, the primates suggested include *Kenyapithecus*, *Griphopithecus*, *Dryopithecus*, *Graecopithecus* (*Ouranopithecus*), *Samburupithecus*, *Sahelanthropus*, and *Orrorin*. *Kenyapithecus* inhabited Kenya and *Griphopithecus* lived in central Europe and Turkey from about 16 to 14 mya. *Dryopithecus* is best known from western and central Europe, where it lived from 13 to possibly 8 mya. *Graecopithecus* lived in northern and southern Greece about 9 mya, at roughly the same time as *Samburupithecus* in northern Kenya. *Sahelanthropus* inhabited Chad between 7 and 6 mya. *Orrorin* was from central Kenya 6 mya. Among these, the most likely ancestor of great apes and humans may be either *Kenyapithecus* or *Griphopithecus*.

Among evolutionary models that stress the Eurasian species, some consider *Graecopithecus* to be ancestral only to the lineage containing *Australopithecus*, *Paranthropus*, and *Homo*, whereas others entertain the possibility that *Graecopithecus* is close to the ancestry of *Pan* (chimpanzees and bonobos) and *Gorilla* as well. In the former model, *Dryopithecus* is ancestral to *Pan* and *Gorilla*. On the other hand, others would have *Dryopithecus* ancestral to *Pan* and *Australopithecus* on the way to *Homo*, with *Graecopithecus* ancestral to *Gorilla*. This morphology-based model mirrors results of some molecular studies, which show chimpanzees, bonobos, and humans to be more closely related to one another than any of them is to gorillas; orangutans are more distantly related.

Uncertain origins

In a phylogenetic model that emphasizes African Miocene species, *Samburupithecus* is ancestral to *Australopithecus*, *Paranthropus*, and *Orrorin*, and *Orrorin* begets *Australopithecus afarensis*, which is ancestral to *Homo*.

The Miocene Epoch was characterized by major global climatic changes that led to more seasonal conditions with increasingly colder winters north of the Equator. By the Late Miocene, in many regions inhabited by apes (hominoid primates), evergreen broad-leaved forests were replaced by open woodlands, shrublands, grasslands, and mosaic habitats, sometimes with denser-canopied forests bordering lakes, rivers, and streams. Such diverse environments stimulated novel adaptations involving locomotion

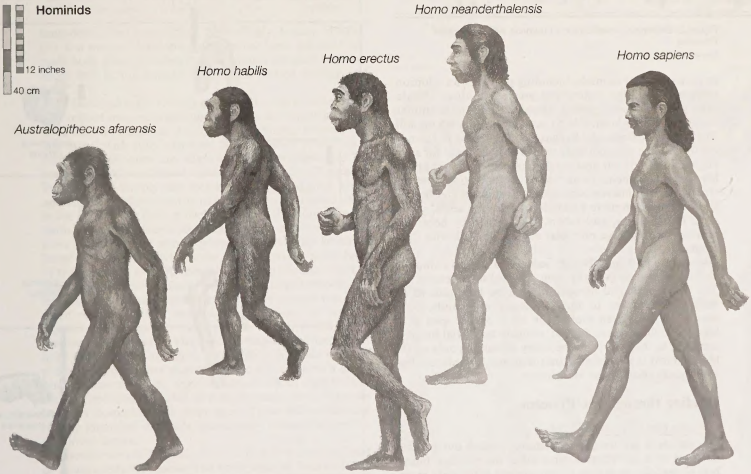

Figure 1: Representative hominids (family Hominidae).
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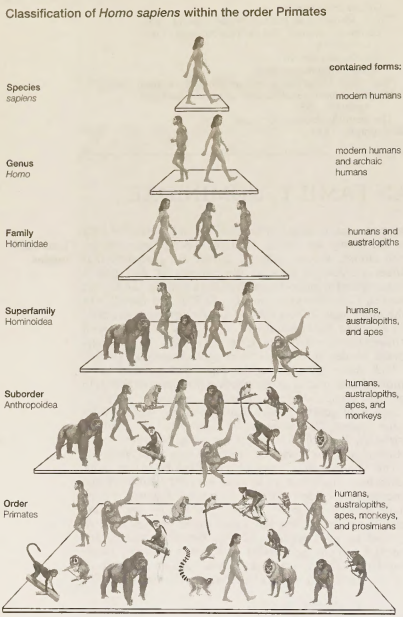

Figure 2: Zoological classification of humans within the order Primates.
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in many types of animals, including primates. In addition, there were a larger variety and greater numbers of antelope, pigs, monkeys, giraffes, elephants, and other animals for adventurous hominids to scavenge and perhaps kill. But large cats, dogs, and hyenas also flourished in the new environments; they not only would provide meat for scavenging hominids but also would compete with and probably prey upon them. In any case, our ancestors were not strictly or even heavily carnivorous. Instead, a diet that relied on tough, abrasive vegetation, including seeds, stems, nuts, fruits, leaves, and tubers, is suggested by hominoid remains bearing large premolar and molar teeth with thick enamel.

Behaviour and morphology associated with locomotion also responded to the shift from arboreal to terrestrial life. The development of bipedalism enabled hominids to establish new niches in forests, closed woodlands, open woodlands, and even more open areas over a span of at least 4.5 million years. Indeed, obligate terrestrial bipedalism (that is, the ability and necessity of walking only on the lower limbs) is the defining trait required for anthropological classification in the Hominidae.

Striding through the Pliocene

THE ANATOMY OF BIPEDALISM

Bipedalism is not unique to humans, though our particular form of it is. Whereas most other mammalian bipeds hop or waddle, we stride. *Homo sapiens* is the only mammal that is adapted exclusively to bipedal striding. Unlike most other mammalian orders, the primates have hind-

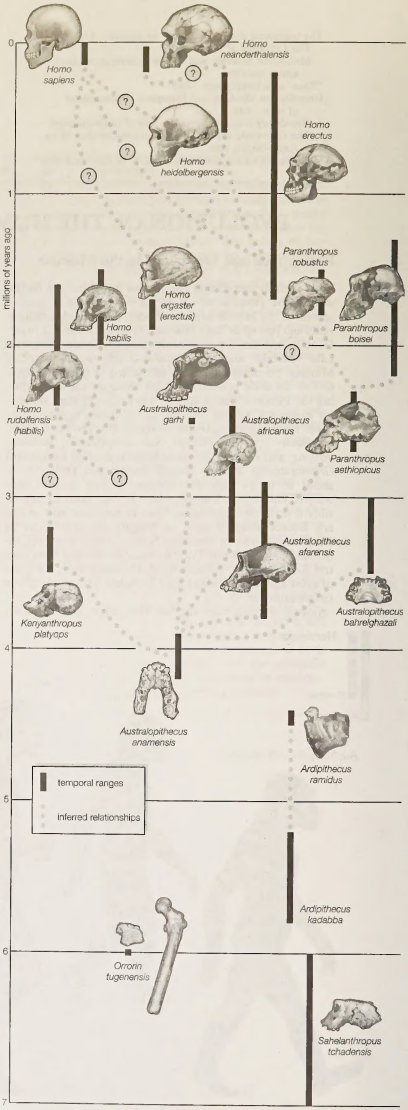

Figure 3: Possible phylogenies of *Homo sapiens*.
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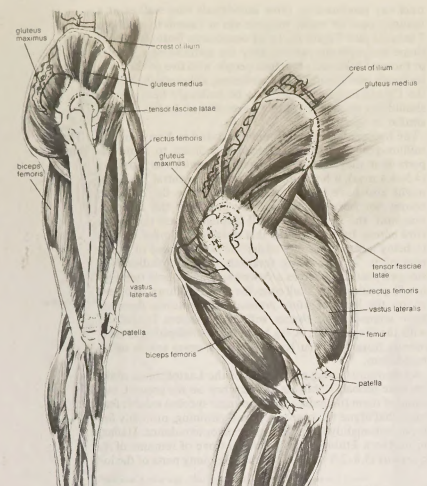

Figure 4: Right leg of a modern human and a gorilla.
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limb-dominated locomotion. Accordingly, human bipedalism is a natural development from the basic arboreal primate body plan, in which the hind limbs are used to move about and sitting upright is common during feeding and rest.

The initial changes toward an upright posture were probably related more to standing, reaching, and squatting than to extended periods of walking and running. Human beings stand with fully extended hip and knee joints, such that the thighbones are aligned with their respective leg bones to form continuous vertical columns (see Figure 4). To walk, one simply tilts forward slightly and then keeps up with the displaced centre of mass, which is located within the pelvis. The large muscle masses of the human lower limbs power our locomotion and enable a person to rise from squatting and sitting postures. Body mass is transferred through the pelvis, thighs, and legs to the heels, balls of the feet, and toes. Remarkably little muscular effort is expended to stand in place. Indeed, our large buttock, anterior thigh, and calf muscles are virtually unused when we stand still. Instead of muscular contraction, the human bipedal stance depends more on the way in which joints are constructed and on strategically located ligaments that hold the joints in position. Fortunately for paleoanthropologists, some bones show dramatic signs of how a given hominid carried itself, and the adaptation to obligate terrestrial bipedalism has led to notable anatomic differences between hominids and great apes. These differences are readily identified in fossils, particularly those of the pelvis and lower limbs.

Although we are bipedal, our pelvis is oriented like that of quadrupedal primates. The early bipedal hominids assumed erect trunk posture by bending the spine upward, particularly in the lower back (lumbar region). In order to transfer full upper-body mass to the lower limbs and to reposition muscles so that one could walk without assistance from the upper limbs and without wobbling from side to side, changes were required in the pelvis—particularly in the ilia (the large, blade-shaped bones on either side), the ischia (protuberances on which body rests when sitting), and the sacrum (a wedge-shaped bone formed by the fusing of vertebrae). Hominid hip bones have short ilia with large areas that articulate with a short, broad sacrum. Conversely, great-ape hip bones have long ilia with small sacral articular areas, and sacra of the great apes are long and narrow. (See Figure 5.) The human pelvis is unique among primates in having the ilia curved forward so that the inner surfaces face one another instead of being aligned sideways, as in apes and other quadrupeds. Curved ilia situate some of the gluteal muscles on the side of the hip joint, where they steady the pelvis as the foot swings forward during a step. This special mechanism allows us to walk smoothly, with only slight oscillations of the pelvis and without gross side-to-side motions of the upper body. Humans have short ischia (and long lower limbs), facilitating speedy actions of the hamstring muscles, which extend the thigh at the hip joint, while great apes have long ischia (and short hind limbs), which give them powerful hip extension for climbing up trees. Characteristically, a human thighbone is long and has a very large, globular head and a short, round neck; at the knee a prominent lateral ridge buttresses the groove in which the kneecap lies. The femurs are farther apart at the hips than at the knees and slant toward the midline to keep the knees close together. This angle allows anthropologists to diagnose bipedalism even if the fossil is only the knee end of a

Locomotor adaptations

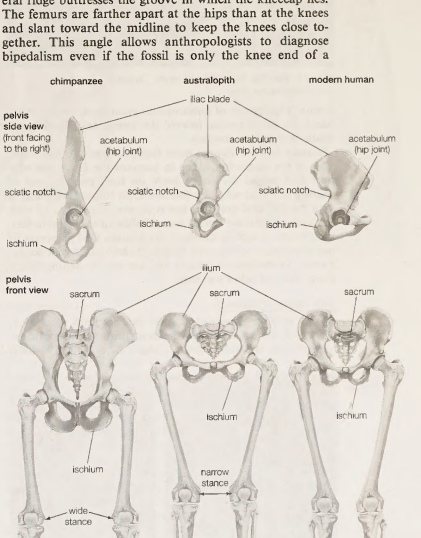

Figure 5: Comparison of the pelvis and lower limbs of a chimpanzee, an australopith, and a modern human.
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Figure 6: Hominid footprints at Laetoli, Tanzania.
John Reader/Photo Researchers

femur. The femurs of quadrupedal great apes, on the other hand, do not converge toward the knees, and the femoral shafts lack telltale angling.

Human feet are distinct from those of apes and monkeys. This is not surprising, since in humans the feet must support and propel the entire body on their own instead of sharing the load with the forelimbs. In humans the heel is very robust, and the great toe is permanently aligned with the four diminutive lateral toes. Unlike other primate feet, which have a mobile midfoot, the human foot possesses (if not requires) a stable arch to give it strength. Accordingly, human footprints are unique and are readily distinguished from those of other animals.

THE FOSSIL EVIDENCE

By 3.5 million years ago at least one hominid species, *A. afarensis*, was an adept walker. In addition to anatomic evidence from this time, there is also a 27.5-metre (90-foot) trackway produced by three individuals who walked at a leisurely pace on moist volcanic ash at Laetoli in northern Tanzania (see Figure 6). In all observable features of foot shape and walking pattern, they are astonishingly similar to those of habitually barefoot people who live in the tropics today (see Figure 7). Nevertheless, although the feet of the Laetoli hominids appear to be strikingly human, one should not assume that other parts of their bodies were as similar to ours.

The first bipeds

The fragmentary femoral remains found in Kenya of six-million-year-old *Orrorin tugenensis* indicate to some experts that they, too, were bipeds. *Ardipithecus ramidus* (4.5–4.4 mya), a hominoid from Aramis, central Ethiopia, might also have been bipedal. In this case the evidence comes not from the lower body but from the foramen magnum, the hole in the skull through which the spinal cord enters. In *Ardipithecus* this opening is similar to ours in being located centrally under the skull instead of at the rear of it. A rear-facing foramen magnum indicates a stooped posture, whereas a downward-facing hole (see Figure 8) positions the skull atop the spinal column. However, on the basis of other craniodental features, theorists have aligned *Ardipithecus* with chimpanzees instead of with the Hominidae. A leg bone of *Australopithecus anamensis* from northern Kenya (4.2–3.9 mya) attests to its bipedalism.

All hominids living at the time of the Laetoli track makers were probably obligate bipeds when on the ground, but some of them (including some younger species) exhibit features that argue for regular arboreal climbing, probably for food, rest, nightly lodging, and predator avoidance. Hadar, in northern Ethiopia, has yielded a trove of remains of *A. afarensis* (3.8–2.9 mya). They include many parts of the lo-

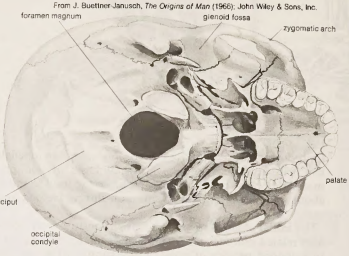

Figure 8: Base of hominid skull.



Figure 7: (Left) Single Laetoli footprint. (Right) Modern footprint of an indigenous Peruvian.
John Reader/Photo Researchers; Russell Tuttle

comotor skeleton that reveal a bipedal habit: short ilia, a wide and stout sacrum, and femoral angling, among other features. At the same time, the curved fingers and toes, laterally flared ilia, and short femurs with long upper limbs, as well as the configuration of its rib cage, indicate that they could readily climb and maneuver in trees. *A. bahrelghazali* (3.5–3.0 mya) of central Chad and *Kenyanthropus platyops* (3.5–3.2 mya) from northern Kenya are represented solely by teeth and by skull and jaw fragments from which positional behaviour cannot be inferred.

Parts of the locomotor skeletons of later hominids such as *A. africanus* (3.3–2.4 mya) and *Paranthropus robustus* (1.8–1.5 mya) of South Africa do not differ markedly from those of *A. afarensis*. The locomotor skeleton of eastern African *P. boisei* (2.2–1.3 mya) is poorly known, but there is no reason to assume that it was different from other *Paranthropus* species. Bouri, a 2.5-million-year-old site in central Ethiopia, yielded arm and leg bones that are contemporaneous with craniodental remains of *A. garhi*. The femur is elongated relative to the humerus, as in *H. sapiens*, but, unlike the human forearm, that of the fossil specimen is relatively long. Thus, by 2.5 mya at least one hominid species had developed the long femurs of striding bipeds, though it retained long forearms like arboreally active *Australopithecus* and *Paranthropus*.

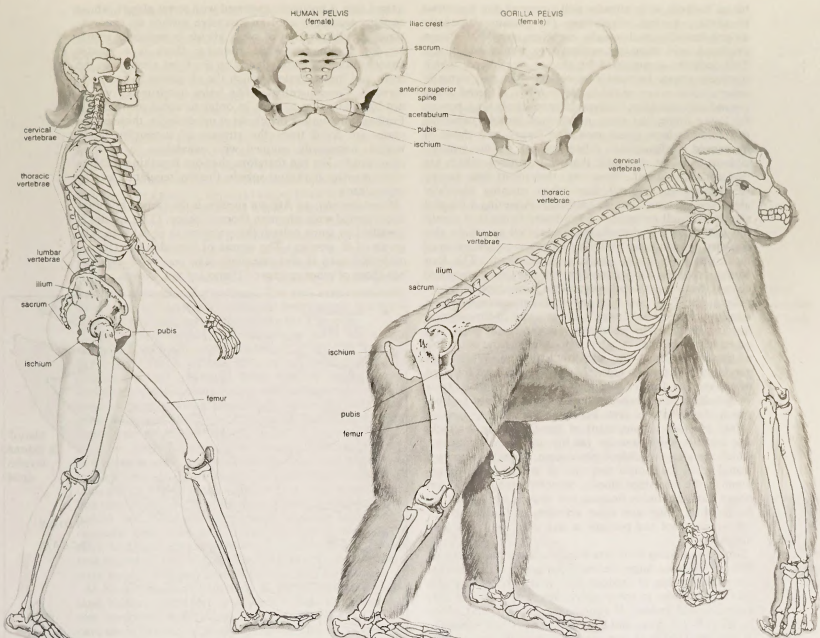

Figure 9: Skeletal comparison of a modern human (a biped) and a gorilla (a quadruped).
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Homo habilis (2.0–1.5 mya), best known from Olduvai Gorge, Tanzania, exhibits small teeth and a large brain, but it has long upper limbs (especially the forearms), short femurs, curved finger bones, and other chimpanzee-like traits that indicate a mélange of arboreal and terrestrial adaptations. Because of these similarities, some investigators classify *H. habilis* as *A. habilis*.

The pelvis of *H. heidelbergensis* (600,000–200,000 years ago, or 600–200 kya) and that of Neanderthals (200–30 kya) are distinct from the pelvis of *H. sapiens* in some features that recall those of *Australopithecus*. The pelvis is broad, with ilia flaring out to the side. The femoral necks are also relatively long. These features are related to stabilizing the pelvis in stocky bipedal hominids. The pelvises of both *H. heidelbergensis* and Neanderthals could accommodate a wider birth canal. This feature is important because they may have had notably larger brains (about 1,200 grams [2.65 pounds] and 1,500 grams [3.28 pounds], respectively) than earlier hominids did—a trait that is reflected in the size of the fetal skull.

Regrettably, development of foot structure in early *Homo*—*i.e.*, between *A. afarensis* and Neanderthals—is virtually undocumented by skeletal evidence. Nonetheless, it is safe to assume that by about 1.5 mya the uniquely human locomotor and associated cooling systems were basically established. Subsequent alterations in pelvic shape may be related to the passage of larger-brained babies through the birth canal.

THEORIES OF BIPEDALISM

Reasons for walking upright

There are many theories that attempt to explain why humans are bipedal, but none is wholly satisfactory. Increased speed can be ruled out immediately because humans are not very fast runners. Because bipedalism leaves the hands free, some scientists, including Darwin, linked it to tool use, especially tools for defense and hunting—*i.e.*, weapons. This theory is problematic in that the earliest stone artifacts date only to about 2.6 mya, long after hominids had become bipedal, thus requiring an assumption that earlier tools were made of wood or other perishable materials.

Twentieth-century theories proposed a wide array of other factors that might have driven the evolution of hominid bipedalism: carrying objects, wading to forage aquatic foods and to avoid shoreline predators, vigilantly standing in tall grass, presenting phallic or other sexual display, following migrant herds on the savanna, and conserving energy (bipedalism expends less energy than quadrupedism). Furthermore, if the early bipeds were regularly exposed to direct midday tropical sunlight, they would benefit from standing upright in two ways: less body surface would be exposed to damaging solar rays, and they would find relief in the cooler air above the ground.

Some scientists assume that the pre-bipedal hominoids were terrestrial quadrupeds, perhaps even knuckle-walkers like modern-day chimpanzees, bonobos, and gorillas (see Figure 9). Conversely, it is also possible that the first ha-

bitual walkers were already well prepared for terrestrial bipedality, having adaptations for running bipedally among branches and boughs, standing upright to forage overhead, and climbing vertical tree trunks and vines. This scenario is suggested by studies of gibbons, which routinely engage in these arboreal activities and virtually never elect to move on the forest floor but, if forced to the ground, run bipedally. Gibbons have relatively long, powerful lower limbs, the same number of lumbar vertebrae that humans have (great apes have fewer), and chests of humanoid configuration. When walking on the ground, gibbons stand up straighter than chimpanzees, which are occasionally bipedal. Moreover, they exert less energy running on the ground than when running bipedally along branches or climbing vertically. Adopting a bipedal stance with full extension of the lower limbs thus would not have been a major challenge, since all apes have this capacity, though there would have been some alteration of the lower limb bones, joints, and ligaments. The foot would probably have gone through the most dramatic change, from a prehensile organ to a heel-supported, propellent one. Increased size and frequent, sustained erect standing on extended lower limbs in order to forage overhanging branches in woodland, thicket, forest edge, and other relatively open habitats would favour the evolution of humanoid hip, knee, and foot structure. While consuming their harvests, bipedal foragers may have squatted often, thereby further selecting for robust heels and for weight distribution between the heel and forefoot and between closely placed feet. Frequent squatting and rising would enhance development of the hamstring, buttock, and anterior thigh muscles (as hip and knee extensors), which are vital for athletic bipedalism. Stretching upward would select for shorter toes and an arched foot. Refinement of the terrestrial bipedal complex probably did not occur until hominids became less dependent upon trees for daytime refuge and other activities and began to forage widely afoot and perhaps to trek seasonally over long distances.

Size considerations

Simply increasing body size would increase locomotor efficiency, because larger animals can more effectively use the elastic energy of tendons and muscles, and they also take fewer strides to cover a given distance than a smaller animal would. Indeed, *H. rudolfensis* (2.4–1.6 mya), *H. ergaster* (1.9–1.7 mya), and later species of *Homo*, including *H. sapiens* (100 kya), are notably taller and heavier than *Australopithecus* and *Paranthropus*. There is less size difference between the sexes in *Homo* species than in many other primates, largely because the females have become larger. Average size in male *Australopithecus* (41–51 kilograms [90–112 pounds]) and *Paranthropus* (40–49 kilograms [88–108 pounds]) is comparable to that of male chimpanzees (49 kilograms). The size of females (30–33, 32–34, and 41 kilograms, respectively) indicates that there was more difference between the sexes (sexual dimorphism) in these hominids than there is in chimpanzees. Sexual dimorphism in *H. rudolfensis* (60 versus 51 kilograms [132 versus 112 pounds]) and *H. ergaster* (66 versus 56 kilograms [145 versus 123 pounds]) is comparable to that in *H. sapiens* (58 versus 49 kilograms [128 versus 108 pounds]).

Homo rudolfensis and *H. ergaster* have long femurs of modern human configuration and internal knee structure like that of *H. sapiens*; both structures are quite unlike those of chimpanzees and at least some of the smaller tree-climbing hominids. This may have been the time also when the distinctive morphology of the human calf muscle (triceps surae) evolved. Unlike those of great apes, it is heavily tendinous, which facilitates its function as an energy-conservant spring during walking and running.

The unique epidermal and respiratory mechanisms of *H. sapiens* may also have developed in conjunction with regular trekking, sprinting, and endurance running as ancestral *Homo* secured a foothold in open tropical and subtropical environments. There is a rich concentration of sweat glands in our scalp (apes have few or none in theirs), which helps to cool the head, especially the brain, in high temperatures and during vigorous activity. Postcranially, our abundantly vascular and highly sensitive sparsely haired skin is profusely endowed with sweat glands, whose copious secretions cool an extensive surface by evaporation. The distribution of sweat glands is especially strategic for cooling us while running: there is a greater concentration of sweat glands on the front surfaces of the torso and limbs, against which the air passes as we move forward. Consequently, unlike hairy quadrupeds, we do not have to pause to pant in order to avoid overheating. Furthermore, unlike the chests of quadrupeds, those of humans are freed from the stresses of supporting body weight, necessarily coupled with exhalation in running quadrupeds. We can therefore alter our breathing patterns while moving at various speeds, thereby regulating energy expenditure.

Homo ergaster, an African species, is the earliest hominid documented with a human thoracic shape. (This species is classified by some paleoanthropologists as an African subgroup of *H. erectus*.) The thorax of Neanderthals (*H. neanderthalensis*) is also essentially like that of *H. sapiens*, but those of other species of *Homo* are not known.

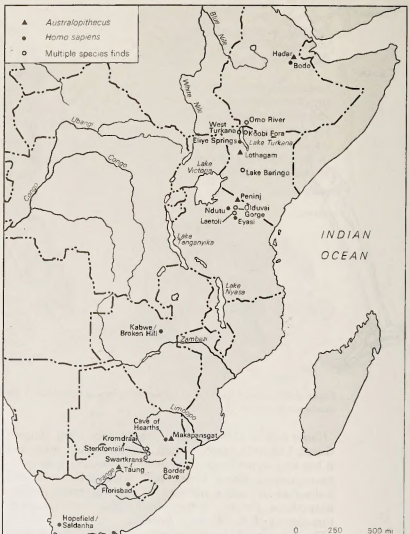

Figure 10: Major sites of hominid fossil finds in eastern and southern Africa.

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Hominid habitats

As described above, global climatic changes reduced forested areas and induced more open terrestrial biomes during the Late Miocene Epoch (11.2–5.3 mya). During the succeeding Pliocene Epoch (5.3–1.6 mya) these changes only intensified. In Africa, hominoids diversified. In Eurasia, contrarily, hominids disappeared by the beginning of the Pliocene. The only descendants of Late Miocene hominoids in Asia are the extinct Early-Middle Pleistocene *Gigantopithecus blacki* of southern China and northern Vietnam and the present-day orangutans and gibbons of South and Southeast Asia.

It is reasonable to expect that the increased variety and shifting distribution of African biomes stimulated new

hominid lifeways, some of which led to survival and others of which did not. Insofar as habitats have been (or can be) discerned from evidence found with the Pliocene hominid species, hominids inhabited a variety of biomes in eastern, central, and southern Africa. In central Ethiopia, *Ardipithecus ramidus* is associated with faunal and floral remains indicating a woodland habitat. Later remains, in northern Ethiopia, indicate *Australopithecus afarensis* inhabited a mosaic of riverine forest, lowland woodland, savanna, and dry bushland. In northern Kenya *Australopithecus anamensis* lived in dry open woodland or bushland with a gallery forest along a nearby river. In central Chad the northernmost and westernmost species, *Australopithecus bahrelghazali*, appears to have lived in a mosaic of open and wooded biomes near a river. Mammalian fossils from Lomekwi, northern Kenya, indicate that *Kenyanthropus platyops* inhabited a relatively well-watered area of forest or closed woodland or the forest edge between them. The habitat of the 3.5-million-year-old Laetoli hominids in northern Tanzania was arguably a mosaic of open grassland and more-closed woodland. The area may have been wetter than it is now. No permanent water source has been identified for the Laetoli area during the Pliocene.

Later in the Pliocene, *Australopithecus garhi* was active on broad, grassy plains bordering a lake in central Ethiopia. Models of the habitat of *Australopithecus africanus*, based on fauna from the two major South African cave sites—Sterkfontein and Makapansgat—stress closed-canopy wooded conditions: either dry woodland with grasslands nearby or subtropical forest. During the tenures of *H. habilis* and *P. boisei* at Olduvai Gorge, northern Tanzania, the climate changed from moist to dry and again to moist before a long dry span that began two million years ago. Specimens of both of these Olduvai hominids are mostly from the shore of an ancient saline, alkaline lake. At Koobi Fora, northern Kenya, specimens of *H. habilis* have been more commonly found in lake-margin deposits, while those of *P. boisei* are equally common in river and lake-margin sediments. Fossil pollen indicates that highland forest was nearby and that near the lake there were grassy areas and dense woodland and shrubland.

Climate changes at Olduvai Gorge

At Konso, southern Ethiopia, *P. boisei* lived in a grassland habitat. Elsewhere in eastern Africa, *P. aethiopicus* was associated with closed habitats. The South African cave sites (Swartkrans, Kromdraai, and Drimolen) of *P. robustus* are associated with open and even arid habitats, but these may not reflect its actual foraging preference.

One of the more profound effects of Pliocene habitat changes was honing the energy-conservant bipedal stride at the time that *Homo* species deployed out of Africa and into Eurasia. Shortly after *Homo* evolved in Africa, some species ventured to temperate biomes in Eurasia and then to subtropical and tropical biomes in South and Southeast Asia. Subsequently there was a migration back to Africa, perhaps as early as 1.8–0.9 mya. This hemispheric dispersion of *Homo* is associated with elaboration of stone tool kits, increased brain size, and reduction in size of the jaws and teeth—all of which are the subject of the next section.

Tools, hands, and heads in the Pliocene and Pleistocene

REFINEMENTS IN HAND STRUCTURE

Primates are hand-to-mouth feeders that pluck and catch items selectively by hand before ingesting them. Without tools, emergent hominids would have relied on the versatility and strength of their hands to collect food and on their teeth and jaws alone to process it. Unless they used tools to fashion carrying devices such as bags from animal skins, they would have needed a reliable source of water nearby, and they would also have been limited in the types and number of objects that they could transport through their range. In addition to transporting objects and water, there is the more obvious utility of animal skins in protecting against night chills, rain, and strong sunshine.

Sharp-edged stones, even small flakes, would be a boon to early hominids who learned how to select and make them for cutting hides, meat, sticks, and other plant material. Stones also would assist in pounding open hard-shelled fruits and nuts, bones for marrow, and skulls for brains. There may have been a span when early hominids used naturally occurring stones and other objects as tools and weapons, much as some wild chimpanzees do today.

Before hominids controlled fire and either built sturdy shelters on the ground or effectively defended caves and rock shelters, they may have constructed platforms in trees for daily activities as well as night lodging. Raw materials, stone hammers, cutting tools, and sticks and stones for defense could be stored in the trees to be used repeatedly. Handheld rocks, clubs, and long stabbing sticks, spears, or other missiles would constitute a formidable defense, especially if employed from the vantage of a tree platform.

By about 2.6 mya, some hominids were making and using simple stone artifacts in eastern Africa. A likely candidate for this practice is *H. habilis*, though its contemporaries *P. boisei* and *A. garhi* cannot be overruled for this distinction. Indeed, at Bouri, Ethiopia, mammalian bones that were cut and pounded by stone tools occur in 2.5-million-year-old sediments contemporaneous with those yielding *A. garhi*.

Other primates use tools

Because the earliest stone artifacts were of such simple construction and because chimpanzees, orangutans, and capuchin monkeys today can employ stones, stems, vines, and sticks to extract nutritious morsels from protective covers, one need not expect that early hominid toolmakers displayed modern hand structure and exquisite motor control. Nonetheless, the unique structure of the human hand is readily explained by a substantial history of producing and using increasingly complex tool kits and other artifacts. (Attributing specific advancements in artifact manufacture to the threefold increase in brain size between Pliocene hominids and *Homo sapiens* is a much more difficult hypothesis to support, as will be discussed later in this section.)

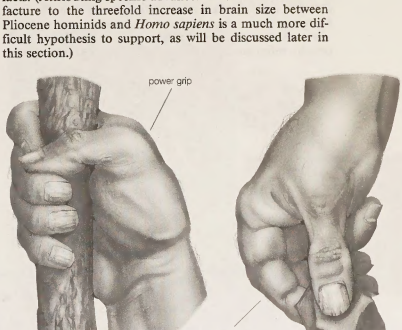

Figure 11: The structure of the human hand allows two specialized grips.
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The features of human hands are easily distinguishable from those of the great apes, and they underpin our refined manipulatory abilities. The most complex adaptations of the human hand involve the thumb, wherein a unique, fully independent muscle (the flexor pollicis longus) gives this digit remarkable strength in precision and power grips (see Figure 11). The fingertips are broad and equipped with highly sensitive pads of skin. The proportional lengths of the thumb and other fingers give us an opposable thumb with precise, firm contact between its tip and the ends of each of the other fingers. A special saddle joint and associated ligaments at the base of the thumb facilitate refined rotation. Special configurations of joints at the bases of the fifth, fourth, and second fingers facilitate tip-to-tip precision grips with the thumb. Asymmetry of the heads of the second and fifth palm bones induces rotation of the articulated fingers during opposition with the thumb. Finally, numerous modifications of the small muscles in the hand are associated with fine control of the thumb and fingers.

Australopithecus afarensis is the earliest hominid species

for which there are sufficient fossil hand bones to assess manipulatory capabilities. They were capable of gripping sticks and stones firmly for vigorous pounding and throwing, but they lacked a fully developed human power grip that would allow cylindrical objects to be held between the partly flexed fingers and the palm, with counterpressure being applied by the thumb. There are insufficient specimens to assess fine manipulation in *Australopithecus*, but there is no reason to believe that they were less capable than modern chimpanzees. Chimpanzees and other apes have remarkable precision of grip, even though the tapered thumb tip must be pressed against the side of the index finger and cannot be apposed securely to any of the fingertips.

Hand bones assigned to a 1.8-million-year-old specimen of *H. habilis* from Olduvai Gorge in northern Tanzania represent an advance over those of *A. afarensis* in features related to tool use. Tools similar to those found at Olduvai are found associated with *H. habilis* from other parts of eastern Africa as well. The tips of its thumb and fingers were flat, and there is evidence for a strong flexor pollicis longus muscle and a saddle joint at the base of the thumb. Hand bones arguably assigned to *P. robustus* or *Homo* from Swartkrans, South Africa, confirm that by about 1.8 mya one or more hominid species had highly developed thumbs and flat fingertips.

Hominid hand bones from 2.8–2.5-million-year-old cave deposits at Sterkfontein, South Africa, may be evidence that the hands of *A. africanus* were somewhat more advanced for stone tool use, but no artifact has been found in association with them. Younger Sterkfontein deposits (2.0–1.5 mya) contain stone artifacts and remains of a *Homo* species.

Because of an absence of fossils, it is not possible to track certain refinements in hand structure that must have evolved in conjunction with innovations in tool manufacture and use during the heydays of *H. rudolfensis*, *H. ergaster* (1.9–1.7 mya), and *H. erectus* (1.7–0.2 mya), as well as *H. antecessor* (1.0–0.8 mya) and *H. heidelbergensis* (600–200 kya). Only prehistoric and modern *H. sapiens* and *H. neanderthalensis* are fully represented by hand skeletons.

INCREASING BRAIN SIZE

Because more complete fossil heads than hands are available, it is easier to model increased brain size in parallel with the rich record of artifacts from the Paleolithic Period (2,500,000 to 10,000 years ago), popularly known as the Old Stone Age. Indeed, so easy is it to link hominid brain expansion with refinements in tool technology that one can do so simply by ignoring other possible causal factors, such as social complexity, foraging strategies, symbolic communication, and capabilities for other culture-mediated behaviours that left no or few archaeological traces.

Throughout human evolution, the brain has continued to expand (see Figure 12). Estimated average brain masses of *A. afarensis* (435 grams [0.96 pound]), *A. garhi* (445 grams [0.98 pound]), *A. africanus* (450 grams [0.99 pound]), *P. boisei* (515 grams [1.13 pounds]), and *P. robustus* (525 grams [1.16 pounds]) are close to those of chimpanzees (395 grams [0.87 pound]) and gorillas (490 grams [1.08 pounds]). Average brain mass of *H. sapiens* is 1,350 grams (2.97 pounds). The increase appears to have begun with *H. habilis* (700 grams [1.53 pounds]), which is also notable for having a small body. The trend in brain enlargement continued in Africa with larger-bodied *H. rudolfensis* (735 grams [1.62 pounds]) and especially *H. ergaster* (850 grams [1.87 pounds]).

Brain masses

One must be extremely cautious about ascribing greater cognitive capabilities, however. Relative to estimated body

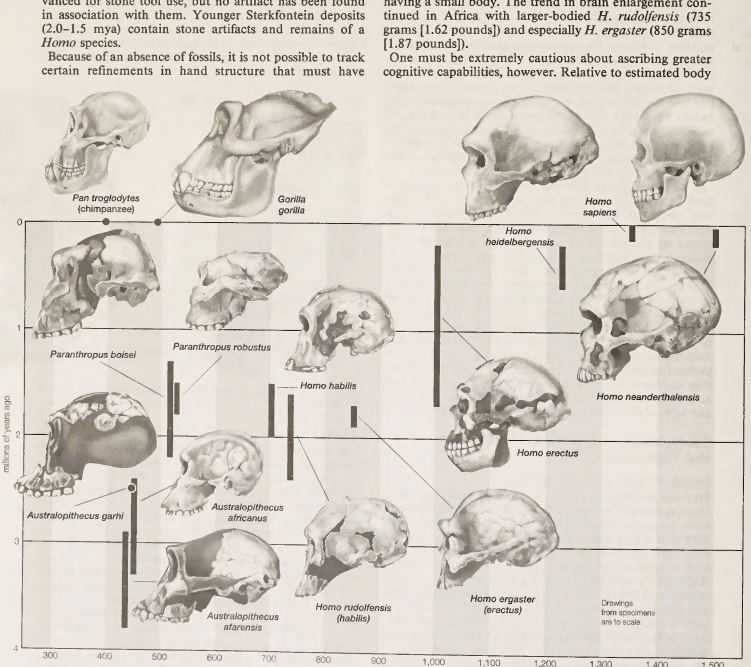

Figure 12: The increase in hominid cranial capacity over time.

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mass, *H. habilis* is actually "brainier" than *H. rudolfensis* and *H. ergaster*. A similar interpretive challenge is presented by Neanderthals versus modern humans. Neanderthals had larger brains than earlier *Homo* species, indeed rivaling those of modern humans. Relative to body mass, however, Neanderthals are less brainy than anatomically modern humans. Relative brain size of *Homo* did not change from 1.8 to 0.6 mya. After about 600 kya it increased until about 35,000 years ago, when it began to decrease. Worldwide, average body size also decreased in *H. sapiens* from 35,000 years ago until very recently, when economically advanced peoples began to grow larger while less-privileged peoples did not.

The unreliability of brain size to predict cognitive competence and ability to survive in challenging environments is underscored by the discovery of a distinctive human sample, dubbed *Homo floresiensis*, in a limestone cave on Flores island, Indonesia, in 2003–04. The diminutive *H. floresiensis* had a brain comparable in mass to those of chimpanzees and small australopiths but produced a stone tool industry comparable to that of Early Pleistocene hominids and survived among giant rats, dwarf elephants, and Komodo dragons from at least 38 kya to about 18 kya. If these hominids are indeed a distinct species, they constitute yet another archaic human (in addition to *H. neanderthalensis* and perhaps *H. erectus*) that lived contemporaneously with modern humans during the Late Pleistocene.

REFINEMENTS IN TOOL DESIGN

In Africa the Early Paleolithic (2.5–0.2 mya) comprises several industries with the earliest man-made chipped flakes and core choppers (2.5–2.1 mya). Double-faced hand axes, cleavers, and picks (collectively known as bifaces) appeared about 1.5 mya and persisted until 200 kya. Archaeologists have detected some improvements of technique and product during the half-million-year span of core-flake industries. Although the major biface industry—the Acheulean—has been characterized as basically static, it, too, shows evidence of refinement over time, finally resulting in elegant, symmetrical hand axes that required notable skill to make.

By 1.7 mya a population of *H. erectus* similar to African *H. ergaster* lived in Eurasia at what is now Dmanisi, Georgia. The associated choppers, chopping tools, flakes, and scrapers recall the Oldowan core-flake industry of eastern Africa, but there are no bifaces among them. The braincase of the two Dmanisi specimens is smaller than that of African *H. ergaster*. New geochemical dates for classic hominid localities in Java indicate that *H. erectus* may have lived in Southeast Asia 1.5 mya, but no industry is certainly identified with them.

El 'Ubeidîya, Israel, provides evidence that people and bifaces had spread out of Africa by 1.4 mya. In Europe, Acheulean tools appear 500 kya and persist until about 250–150 kya (see Figure 36); they also occur in South Asia. Sites in China (800 kya), Korea, and Japan contain bifaces, but they differ from Acheulean tools. No such technology has been found in tropical Southeast Asia, where bamboo tools may have sufficed.

In both Africa and Eurasia, where the Middle Paleolithic lasted from 200 to 30 kya, tools are characterized by carefully prepared cores from which elegant flakes were struck. There are many local and regional variations in size, shape, and frequencies of reshaped flakes, blades, scrapers, hand axes, and other tools. Projectile points began to be emphasized in some regions, with bone being used as well as stone.

Diversifying technology

Late Paleolithic industries dating to 50–10 kya comprise diverse blade and microblade tools, especially in Europe. Late Paleolithic peoples used a variety of materials for their tools and bodily ornaments, including bone, stone, wood, antler, ivory, and shell. Stone blades were long, thin, and very effective cutting tools. Often, when they became dull, someone retouched them via pressure flaking, which requires fine motor control and coordination. Microblades and other points were probably hafted to produce throwing and stabbing spears. Other composite tools of the period include atlatls, harpoons, fish weirs, and perhaps bows and arrows. Late Paleolithic people also developed techniques for grinding and polishing, with which they made beads, pendants, and other artistic objects. They also made needles (perhaps for sewing fitted clothing), fish hooks, and fish gorges.

REDUCTION IN TOOTH SIZE

The combined effects of improved cutting, pounding, and grinding tools and techniques and the use of fire for cooking surely contributed to a documented reduction in the size of hominid jaws and teeth over the past 2.5 to 5 million years, but it is impossible to relate them precisely. It is not known when hominids gained control over fire or which species may have employed it thereafter for food preparation, warmth, or protection against predators. It is very difficult to discern whether a fire was deliberately produced by hominids or occurred naturally.

Concentrations of charcoal, burned bones, seeds, and artifacts in China and France suggest that *H. erectus*, *H. heidelbergensis*, or both used fire as early as 400 kya, and possible evidence of 700,000-year-old hearths comes from Israel. Certainly some Middle and Late Paleolithic peoples controlled fire, but hearths are rare until 100 kya. If claims for control of fire in South Africa 1.5 mya are confirmed, *P. robustus* or *H. ergaster* would be the first fire keepers.

Domesticating fire

At first glance early hominid skulls appear to be more like those of apes than humans. Whereas humans have small jaws and a large braincase, great apes have a small braincase and large jaws. In addition, the canine teeth of apes are large and pointed and project beyond the other teeth, whereas those of humans are relatively small and nonprojecting. Indeed, human canines are unique in being incisorlike, and the front lower premolar tooth is bicuspid. In apes and in many monkeys, however, the lower premolar is unicuspid and hones the upper canine tooth to razor sharpness.

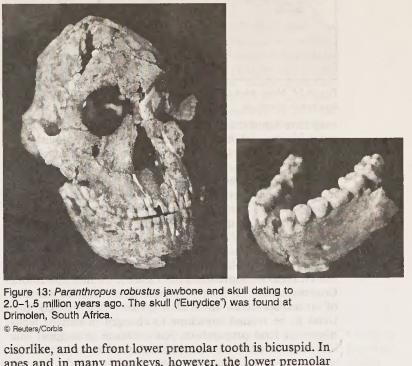

Figure 13: *Paranthropus robustus* jawbone and skull dating to 2.0–1.5 million years ago. The skull ("Eurydice") was found at Drimolen, South Africa.
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In male *Australopithecus* and *Paranthropus* the large chewing muscles needed to power their deep, robust jaws were attached to prominent crests on the braincase and to flaring arches of bone on the face and sides of the skull. Over time the rear teeth of *Paranthropus* increased in size while the incisors and canines shrank. Accordingly, *P. robustus* and *P. boisei* have relatively flat faces and nonprotruding jaws.

Australopithecus species also had large rear teeth, but their faces were more protruding because the incisors and canines were not as reduced as those of *Paranthropus*. Over time the rear teeth progressively increased in size from *A. anamensis* to *A. africanus* and *H. habilis*, with *A. afarensis* intermediate between *A. anamensis* and the younger species of *Australopithecus*. When compared with estimated body size, the pattern of increased tooth size over time is confirmed for *Paranthropus*.

Tooth wear patterns in *A. afarensis* indicate that it may have stripped vegetal foods by manually pulling them across the front teeth. The robust-skulled *Paranthropus*

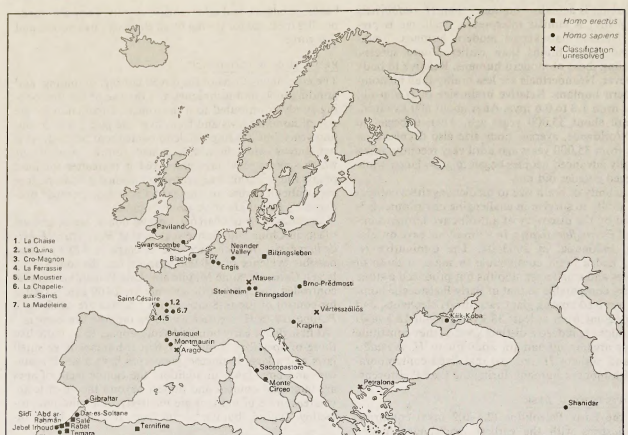

Figure 14: Major sites of hominid fossil finds in Europe, North Africa, and southwestern Asia.
Encyclopædia Britannica, Inc.

may have eaten tougher foods than did gracile-skulled *Australopithecus*. Additionally, some paleoanthropologists believe that *Paranthropus* was vegetarian, while *A. africanus* had more meat in its diet. Dental morphology and wear patterns indicate that in South Africa *P. robustus* ate hard foods and that Kenyan *P. boisei* chewed whole pods and fruits with hard coatings and tough seeds, though they probably did not chew quantities of grass seed, leaves, or bone.

Unlike those of *Paranthropus* and *Australopithecus*, the teeth of *Homo* became smaller over time. *H. rudolfensis* has large rear teeth, even relative to estimated body size, but *H. ergaster* approaches the modern human condition. Concomitantly, the face of *H. rudolfensis* is more like that of *Australopithecus* than *H. ergaster*. One expects this trend to be related somehow to changes in diet or techniques of food preparation, but evidence to support this link is not available in the archaeological record.

The emergence of *Homo sapiens*

The relationships among *Australopithecus*, *K. platyops*, *Paranthropus*, and the direct ancestors of *Homo* are unknown. Because of its early date and geographic location, *A. anamensis* may be the common ancestor of *A. afarensis*, *A. garhi*, *K. platyops*, and perhaps the Laetoli Pliocene hominids of eastern Africa, *A. bahrelghazali* of central Africa, and *A. africanus* of southern Africa. *A. afarensis* in turn may be ancestral to *P. aethiopicus*, which begat *P. boisei* in eastern Africa and *P. robustus* in southern Africa.

Factors indicating *H. rudolfensis* as ancestral to later species of *Homo* are its absolute brain size, large body, and lower limb morphology. These features clearly foreshadow younger species of *Homo* in Africa and Eurasia.

Our ancestry becomes no clearer as the candidates are narrowed to *Homo* species exclusively. Among paleoanthropologists who accept it as a species distinct from *H. erectus*, *H. ergaster* is most often proposed as the ancestor of *Homo* species of the Pleistocene Epoch. *H. heidelbergensis* may have arisen from *H. ergaster*, *H. erectus*, or *H. antecessor*, and any or none of them could have been ancestors of *H. neanderthalensis* and *H. sapiens*. Neanderthal populations, particularly as represented by specimens from western Europe, probably were not ancestral to modern humans.

Theorists use fossil remains, genetic traits of modern people around the world, and archaeological and anatomical indicators of cognitive, linguistic, and technological capabilities to support their models of recent human evolution, but no single theory provides definitive resolution of how *H. sapiens* came to be. The limitations of empirical evidence confound efforts to discern whether distinctive features and lineages developed gradually or over periods of stasis punctuated by rapid change (a theory known as punctuated equilibrium). There are claims for about 20 fossil hominid species over the course of the last six million years, but they are assessed on a case-by-case basis. For example, it appears that Neanderthals (*H. neanderthalensis*) were a dead end for two ancestral species (*H. antecessor* and *H. heidelbergensis*) that changed gradually in Europe from about 700 kya to 30 kya. *H. sapiens* may have evolved similarly through a series of species represented by African specimens, but other theorists envision a dramatic shift in cognitive capacity and behaviour that qualifies instead as a punctuational change. This change would have occurred about 200 kya in one small African population and would have been followed by a long period of stasis that continues to the present. Such a scenario is not unprecedented, as *A. afarensis* was a capable biped that appears to have emerged suddenly and persisted for nearly one million years.

Proposed ancestries

There are four basic models that purport to explain the evolution of *H. sapiens* between 200 and 30 kya. At one extreme is multiregional evolution, or the regional continuity model. At the other is the African replacement, or "out of Africa," model. Intermediate are the African hybridization-and-replacement model and the assimilation model. All but the multiregional model maintain that *H. sapiens* evolved solely in Africa between about 200 and 100 kya and then deployed to Eurasia and eventually the Americas and Oceania. Both of the replacement models

argue that anatomically modern emigrants replaced resident Eurasian and Australasian species of *H. sapiens* with little or no hybridization. The hybridization-and-replacement model proposes some interbreeding with archaic indigenous populations but with relatively minor effects. Assimilation maintains continuity between archaic and modern humans, most notably in some areas of Eurasia, where gene flow and local selective factors would also produce morphological changes. In this model, unity of the species was maintained by periodic interbreeding across wide areas. Multiregionalists reject the idea that *H. sapiens* evolved uniquely in Africa. Instead, they advocate that discrete archaic populations of *Homo* evolved locally in Africa, Asia, and Europe. Throughout their tenures, both the archaic and descendant populations interbred with contemporaries from other areas.

The African replacement model has gained the widest acceptance owing mainly to genetic data (particularly mitochondrial DNA) from existing populations. This model is consistent with the realization that modern humans cannot be classified into subspecies or races, and it recognizes that all populations of present-day humans share the same potential.

Such a tangled line of descent is not surprising given the nomadic lifestyles enabled by bipedalism. There appear to have been successive migrations of hominid species out of Africa, with evolution of new species in Eurasia and occasional migrations back into Africa. For instance, *H. ergaster* may have been the first hominid to reach Eurasia. Some of its descendants could have moved quickly to East and Southeast Asia, where they begat *H. erectus*. Others may have evolved into *H. heidelbergensis*, which populated Europe sparsely and then returned to Africa.

Some paleoanthropologists claim that *H. antecessor*, found in 800,000-year-old cave deposits at Gran Dolina, Sierra de Atapuerca, Spain, was a direct ancestor of *H. neanderthalensis* via *H. heidelbergensis*, which is represented by 300,000-year-old specimens from Sima de los Huesos in the Sierra de Atapuerca. Further, they propose that *H. antecessor*, from million-year-old deposits in Eritrea, is a direct ancestor of *H. sapiens* in Africa.

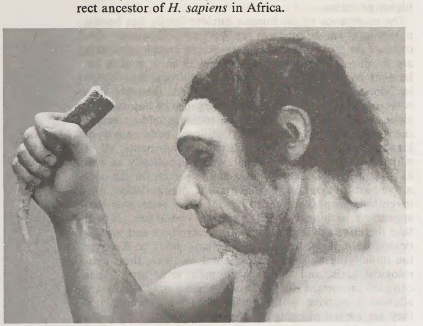

Figure 15: Reconstruction of the appearance of a Neanderthal. Shown are the head and shoulders of a complete statue.
Erik Trinkaus

Neanderthals probably evolved in Europe at least partially in response to cold climatic conditions and then migrated to western Asia, where they may have encountered *H. sapiens* in the Levant. There is no skeletal evidence that they reached the African continent or moved much farther east than Uzbekistan in Central Asia. Features of Neanderthals that argue for adaptation to seasonally frigid biomes include stocky torsos, short limbs (particularly the forearms and legs), and distinctive facial structure. The middle of the face protrudes, the teeth are set forward, the enlarged cheekbones sweep backward, and the nasal passages are voluminous. If Neanderthals wore animal furs and other insulating materials on their heads and bodies while keeping vigorously active in frigid weather, the large nasal chamber would help to cool the blood and prevent overheating the brain, while clothing would reduce the risk of frostbite. The nasal chamber might also conserve moisture during exhalation.

Fossil specimens from Laetoli in Tanzania and from Klasies River Mouth in South Africa indicate that anatomically modern *H. sapiens* evolved sometime between 200 and 100 kya in eastern or southern Africa. Molecular genetic data suggest that early *H. sapiens* passed through a population bottleneck—that is, a period when they were rare creatures—before rapidly spreading throughout the Old World. They replaced indigenous hominid species in Eurasia, and then, as sea levels dropped during glacial periods, adventurous individuals went to sea in watercraft and populated Australia, the Americas, and oceanic islands.

A diminished human population

Some of the extensive variation in bodily proportions, external features, and blood chemistry of modern peoples may reflect adjustments to biomes over geologically short time spans. However, molecular genetic studies show that genomic differences between even far-flung peoples are minuscule compared with variations within each local population. Accordingly, for modern *H. sapiens*, race is a mere cultural construct with no biological basis.

Language, culture, and lifeways in the Pleistocene

SPEECH AND SYMBOLIC INTELLIGENCE

The origin and development of human culture—articulate spoken language and symbolically mediated ideas, beliefs, and behaviour—are among the greatest unsolved puzzles in the study of human evolution. Such questions cannot be resolved by skeletal or archaeological data. Research on the behaviour and cognitive capabilities of apes, monkeys, and other animals and on cognitive development in human children provide some clues, but extrapolating this information back through time is tenuous at best. Complicating the scenario further, it may be that today's chimpanzees, bonobos, and other anthropoid primates have more sophisticated cognitive capabilities and behavioral skills than those of some early hominids, because they and their ancestors have had several million years to overcome many challenges and perhaps have become more advanced in the process. Speech has been inferred by some investigators on the basis of certain internal skull features, for example, in *H. habilis*, but jaw shape and additional traits suggest otherwise. Still other researchers claim that human speech was not even fully developed in early members of anatomically modern *H. sapiens*, because of the simplicity of their tool kits and art before the Late Paleolithic.

Clues to linguistic ability

It is impossible to assess linguistic competency by observing the insides of reassembled fossil craniums that are incomplete, battered, and distorted—and in any case the brains probably did not fit snugly against the walls of the braincase. The apparent cerebral expansion in *H. habilis* and *H. rudolfensis* may imply a general increase in cognitive abilities, manipulative skill, or other factors besides speech. Particularly unreliable are claims that the specific internal cranial impressions of a Broca cap are evidence of speech. Prominent Broca caps exist among some chimpanzees, yet no ape has uttered a word, despite laborious attempts to get them to speak.

A humanoid vocal tract is undetectable in fossils because it comprises only soft tissues and leaves no bony landmarks. Although versatile human speech is reasonably linked to a relatively spacious pharynx and mobile tongue, the absence of such features is not a compelling reason to deny some form of vocal language in ancestral hominids. It is argued that articulate human speech is impossible without a lowered voice box (larynx) and an expanded region above it. If this presumption were true, even Neanderthals would be inept vocally and probably also quite primitive cognitively as compared with Late Paleolithic *H. sapiens* populations such as the Cro-Magnons. Gibbons and great apes do not speak, yet they have throat traits con-

comitant with speech, albeit to a lesser degree than humans'. The calls of gibbons are wonderfully varied in pitch and pattern, and, if such sounds were broken into discrete bits with consonants, they could emulate words. The same may be said for great apes. Orangutans, chimpanzees, and bonobos have sufficiently mobile lips and tongues; they simply lack neural circuitry for speech. The stunning proliferation and stylistic variability of tools, bodily ornaments, and artistic works during the Late Paleolithic probably signals a major cognitive enhancement of symbolic capabilities in our most recent lineage.

Aspects of intelligence

Conversely, if the theory that different abilities are governed by distinct and separate forms of intelligence (multiple intelligences) is correct, much of tool-using behaviour and artistic ability would have to be based upon neurological structures fundamentally different from those that support verbal ability. Visual arts—painting and sculpture—are expressions of spatial intelligence, which is centred principally in areas of the brain different from those related to speech. Therefore, one cannot expect the problem of language origins or language competence to be clarified by studying Late Paleolithic symbolism and imagery, and the awesome array of polished bone, antler, ivory, and stone artifacts and cave art do not inform directly about when speech became a regular or essential component of the human condition. Human children begin to use language before they become sophisticated tool users. Similarly, a form of speech might have preceded forms of tool behaviour that are symbolically mediated.

Historically, all human groups manifest rich symbolically mediated language, religion, and social, political, and economic systems, even in the absence of elaborate material culture. The demands on the social intelligence of peoples who live in environments with relatively few artifacts are similar to demands placed upon those who depend upon complex technological gadgets and shelters for comfort. Consequently, prehistoric *H. sapiens* cannot be regarded as cognitively less capable than ourselves, and it is impossible to state which hominid species were "fully human" as symbol users. As a case in point, meticulously documented language studies of captive bonobos and chimpanzees demonstrate that they have the capability to comprehend and use symbols in order to communicate with humans and with one another, but the use of this potential in the wild remains to be demonstrated. Perhaps the human capacity to symbolically represent feelings, situations, objects, and ideas developed before being commandeered by the several intelligences and before it became a boon to vocal communication.

Archaeological evidence indicates that, like at least some of their Pliocene predecessors, the most recent hominids were probably omnivorous, though how much meat was in their diets and whether they obtained it by scavenging, hunting, or both are poorly documented until 100–200 kya. Stone tools and cut marks on bones at archaeological sites attest to a long history of meat eating in the Hominidae, but this practice could have existed long before stone tools were invented. Like chimpanzees, bonobos, baboons, capuchins, and other primates, early Pliocene hominids may have killed and fragmented vertebrate prey with only their hands and jaws instead of tools. The extent to which our ancestors' hunting, scavenging, or other activities were communal and coordinated via symbolic communication has not been determined.

There is no valid way to estimate group size and composition because there is little evidence of movement patterns, shelters, and graves until the Late Paleolithic. Archaeological traces of human-made shelters occur rarely from 60 kya, then become more common, particularly in regions with notable seasons of inclement weather. The first appearances and development of symbolically based spirituality are also highly elusive because they left no morphological or unarguable archaeological trace until the innovation of writing and ritual paraphernalia. Although some Neanderthals buried their dead, there is little evidence of mortuary ceremony in their graves. Graves of *H. sapiens* from 40 kya sometimes contain grave goods.

LEARNING FROM THE APES

Gorillas, chimpanzees, and bonobos are a rich resource for cultural anthropologists, biologists, and psychologists who speculate on the origins of human society. Gorillas appeal to theorists who stress male dominance and patriarchy. A characteristic gorilla group has one silverback (an older dominant male), one or more subordinate blackback males, adult females outnumbering males, and youngsters of various ages. The silverback is the hub of the cohesive group. Chimpanzee society is also dominated by males, which form a stable core of the group. Chimpanzees and bonobos live in larger groups numbering more than 100 individuals, though they forage, travel, and nest in much smaller bands that vary daily in number and composition. Among chimpanzees there is a top male, followed by several others whose ranks depend upon which other males are present. Bonobos have stronger affiliations between males and females than chimpanzees do, and the organizational hub of bonobo social groups is based on intimate relations among adult females, particularly mothers, which often retain strong bonds with their sons. Adult male bonobos are less strongly bonded with one another than chimpanzee males are. Because bonobos are more pacific and tolerant in social relationships and are highly sexual, they are popular with those who would model our heritage as free of "killer apes." However, observers of apes, Old World monkeys, and other mammals have documented incidents of aggression as well as concern for others in their subjects. Both tendencies are deeply rooted among the higher primates.

The emergence of the human nuclear family has been a particularly knotty problem for Western evolutionary theorists. Like bonobos and chimpanzees, people probably are fundamentally promiscuous, though such mating behaviour is heavily proscribed by the cultures into which individuals are born and reside. Indeed, theorists who wish to construct models of the emergence of hominid societies on the basis of extant ape societies seldom tackle the overriding fact that humans utilize a wide variety of kinship, social, sexual, and political arrangements, all of which are maintained and expressed symbolically as well as practically. Researchers often fail to search for the cognitive basis of symbolic representation, manipulation, and invention in apes, citing instead forms of behaviour that appear to harbinger specific human conditions. It will take the efforts of several scientific disciplines and sophisticated technology, probably over many years, to discover the underlying nature of our mental faculties, their neurological basis, and their development over time. Apes can play important roles in this enterprise only if they are allowed to survive in their natural habitats and only if they are viewed as being on their own evolutionary paths and not merely as steps toward the human condition.

Human social complexity

(R.H.Tu.)

MEMBERS OF THE FAMILY HOMINIDAE

Australopiths

The genus *Australopithecus*, its name meaning "southern ape" in Latin, was a group of extinct creatures closely related to, if not actually ancestors of, modern human beings and known from a series of fossils found at numerous sites in eastern, central, and southern Africa. The various species of *Australopithecus* lived during the Pliocene Epoch, which lasted from 5.3 to 1.8 mya. As characterized by the fossil evidence, they bore a combination of human- and apelike traits. Like humans, they were bipedal (that is, they walked on two legs), but, like apes, they had small brains. Their canine teeth were small like those of humans, but their cheek teeth were large. The genus name refers to the first fossils found, which were discovered in South Africa. Perhaps the most famous specimen of

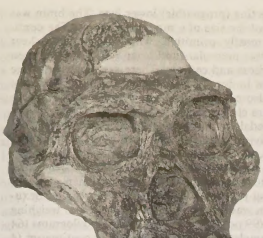

Figure 16: *Australopithecus africanus* skull (STS-5, "Mrs. Ples," replica with reconstruction), found at Sterkfontein, South Africa.
Skulls Unlimited International, Inc.

Australopithecus is "Lucy," a remarkably preserved fossilized skeleton from Ethiopia that has been dated to 3.2 mya.

The general term "australopith" (or "australopithecine") is used informally to refer not only to members of the genus *Australopithecus* but also to other humanlike primates that lived in Africa between 6 and 1.2 mya. Other australopiths include *Sahelanthropus tchadensis* (7–6 mya), *Orrorin tugenensis* (6 mya), *Ardipithecus kadabba* (5.8–5.2 mya), *Ardipithecus ramidus* (4.5–4.4 mya), *Kenyanthropus platyops* (3.5–3.2 mya), and three species of *Paranthropus* (2.7–1.3 mya). Remains older than 6 million years are widely regarded as those of fossil apes. Undisputed evidence of the genus *Homo*—the genus that includes modern human beings—does not appear until about 1.8 mya, in the form of *Homo ergaster*, also called *H. erectus* ("upright man"). The remains of *H. habilis* ("handy man") and *H. rudolfensis* are between 2.5 and 1.5 million years old, but these are difficult to differentiate from those of *Australopithecus*, and the identity of some of these remains is debated.

EARLY SPECIES AND *AUSTRALOPITHECUS ANAMENSIS*

Identifying the earliest member of the human family (Hominidae) is difficult because the predecessors of modern humans are increasingly apelike as the fossil record is followed back through time. They resemble what would be expected in the common ancestor of humans and apes in that they possess a mix of human and ape traits. For example, the earliest species, *S. tchadensis*, is humanlike in having small canine teeth and a face that does not project very far. However, in most other respects, including brain size, it is apelike. Whether it walked upright is not known because only a single skull, jaw fragments, and teeth have been found. Bipedalism may have been established in the six-million-year-old *Orrorin tugenensis*, an australopith found in the Tugen Hills near Lake Baringo in central Kenya. In 2001 these fossils were described as the earliest known hominid. *O. tugenensis* is primitive in most if not all of its body except for femurs (thighbones) that appear to share traits of bipedalism with modern humans. Like later hominids, it has teeth with thick molar enamel, but, unlike humans, it has distinctively apelike canine and premolar teeth. The case for its hominid status rests on the humanlike features of the femur. According to its discoverers, features of the thighbone implying bipedalism include its overall proportions, the internal structure of the knee, and a groove on the bone for a muscle used in upright walking (the obturator externus).

Another candidate for the earliest australopith is *Ardipithecus* (5.8–4.4 mya), found in 1992 at Aramis in the Afar region of Ethiopia. It too is primitive compared with later hominids, though it does share a few evolutionary novelties associated with hominids. Its cranial base is short like that of hominids, and the upper canines are shaped somewhat like those of later species. A well-preserved toe bone shows the characteristically bipedal feature of a base designed for hyperextension while walking. Interestingly, *Ardipithecus* fossils have been found in association with animals usually found in closed woodland habitats rather than open grasslands.

The dawn of *Australopithecus*

The earliest member of the genus *Australopithecus* is *A. anamensis*, discovered in 1994 by a team led by Meave Leakey at Kanapoi and Allia Bay in northern Kenya. The fossils date to 4.2–3.9 mya, and, like *Ardipithecus*, *A. anamensis* is associated with woodland animals and a few grassland species as well. It is quite primitive with a strongly protruding lower face, but at the same time it has certain dental features not seen in *Ardipithecus ramidus*; most conspicuous is a thickening of tooth enamel that becomes characteristic of all later hominids. In addition, the ankle and knee are specialized for upright walking. Other skeletal features are very much like those of later hominids.

In 1998 Leakey's team also discovered *Kenyanthropus platyops* (3.5–3.2 mya) at Lomekwi on the western shore of Lake Turkana in northern Kenya. It too is associated with woodland fauna. It possesses some primitive skull features but shares with early *Homo* a flat and tall face (see

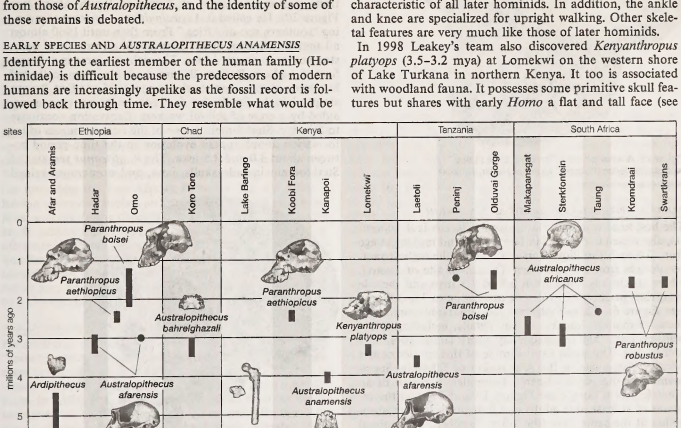

Figure 17: Approximate time ranges of sites yielding australopith fossils.
Encyclopaedia Britannica, Inc.



Figure 18: *Kenyanthropus platyops* skull (replica), found at Lomekwi, near Lake Turkana, Kenya.
Skulls Unlimited International, Inc.

Figure 18). Though it overlaps in time with *A. afarensis* (described below), it appears to be quite distinctive in its morphology and in some respects more primitive. In other respects it resembles much later hominids, particularly *H. rudolfensis*, in having a relatively flat face and small molars. These traits are related to chewing and thus may be related to diet. It is therefore possible that the resemblances between *H. rudolfensis* and *K. platyops* are the result of independent adaptations to similar situations. It is equally possible that the resemblances may imply an evolutionary link between the two.



Figure 19: *Australopithecus afarensis* skull ("Lucy," replica with reconstruction), found at Hadar, Ethiopia.
Skulls Unlimited International, Inc.

AUSTRALOPITHECUS AFARENSIS AND *A. GARHI*

The best-known member of *Australopithecus* is *A. afarensis*, discovered in deposits in East Africa and ranging in age from 3.8 to 2.9 million years old. Part of the earliest sample derives from the northern Tanzanian site of Laetoli, where specimens range from 3.8 to 3.5 mya and include footprints preserved in volcanic ash dating to 3.6–3.5 mya (see Figure 6). These footprints are remarkably similar to those of modern humans in key details, including a forward-pointing big toe, relatively short lateral toes, and arched feet. The main fossil sample of this species comes from Hadar, a site in the Afar region of Ethiopia. Specimens here include a 40-percent-complete skeleton of an adult female ("Lucy"; see Figures 19 and 22) and the remains of at least nine adults and four juveniles buried together at the same time (the "First Family"). The animal fossils found in association with *A. afarensis* imply a habitat of woodland with patches of grassland.

The morphology of *A. afarensis* is a mosaic of primitive features and evolutionary developments shared by later hominids. Its skull is primitive in having a crest and a strongly projecting (prognathic) lower face. The brain was about one-third the size of a modern human's. The dentition is also mostly primitive, with canines that shear against the lower premolars and a gap (diastema) between the upper incisors and canines. There are, however, some dental features in common with later hominids. The rest of the body also combines ape and human traits, but the lower limbs are clearly meant for walking. The most conspicuous bipedal traits include greatly shortened and broadened pelvic blades with a forward-tilted sacrum, convergent knees, horizontally oriented ankles, and a convergent big toe. Primitive features include curved toes and hands, long toes (although much shorter than those of apes), a conical rib cage, and relatively short thighs. Sexual dimorphism was strong in *A. afarensis*, males weighing 45 kilograms (99 pounds) compared with 29 kilograms (64 pounds) for females. Males stood about 151 centimetres (4 feet 11 inches), whereas females were about 105 centimetres (3 feet 5 inches) tall.

Australopithecus reaches Central Africa

In 1995 a lower jaw resembling that of *A. afarensis* came to light from Koro Toro, a site in the Baḥr el-Ghazāl region of northern Chad. It is 3.5–3.0 million years old and was assigned to a new species, *A. bahrelghazali*. In many respects it resembles East African *A. afarensis*, but it differs in significant details of the jaw articulation and teeth. *A. bahrelghazali* is the first Pliocene Epoch hominid known from Central Africa and stretches the geographic range of *Australopithecus* 2,500 kilometres (1,500 miles) westward.

A. garhi (2.5 mya), discovered near Hadar at Bouri in the Afar region of Ethiopia, resembles the more primitive *A. afarensis* more than it does *A. africanus* (described below). *A. garhi* has a projecting lower face, enormous cheek teeth, a shallow palate, a large gap (diastema) between the incisor and canine teeth, and forward-pitched incisors. Relative to the length of the upper arm, its thigh is elongated in a way approaching *Homo*, but its forearm is relatively long, as in apes. *A. garhi* is found in association with animal bones bearing cut marks that may indicate one of the earliest occurrences of tool use.

AUSTRALOPITHECUS AFRICANUS

In 1925 anthropologist Raymond Dart coined the genus name *Australopithecus* to identify a child's skull recovered from mining operations at Taung in South Africa (see Figure 20). He called it *Australopithecus africanus*, meaning "southern ape of Africa." From then until 1960 almost all that was known about australopiths came from limestone caves in South Africa. The richest source is at Sterkfontein, where Robert Broom and his team collected hundreds of specimens beginning in 1936. At first Broom simply bought fossils, but in 1946 he began excavating, aided by a crew of skillful workers. Excavation continues to this day. Sterkfontein is one of the richest sources of information about human evolution in the time period between about 3.0 and 2.5 mya. The *A. africanus* remains of Sterkfontein include skulls, jaws, and numerous skeletal

Sterkfontein

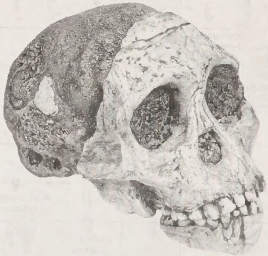

Figure 20: *Australopithecus africanus* skull ("Taung child," replica with reconstruction), found at Taung, South Africa.
Skulls Unlimited International, Inc.

fragments. In 1947 a partial skeleton was unearthed that revealed the humanlike specializations for bipedalism now known to be characteristic of all australopiths. Almost all of the *A. africanus* remains from Sterkfontein come from a deposit where there is a conspicuous absence of stone tools. An older deposit contains a beautifully preserved skeleton and skull of what might be an early variant of *A. africanus*. Another source of *A. africanus* is at Makapansgat, South Africa, where Dart and his team collected about 40 specimens during expeditions from 1947 to 1962.

A. africanus is assigned only an approximate geologic age because the only dating method applicable is biostratigraphy. This indirect method compares accompanying animal fossils with those found in other African sites that have been dated more precisely using radiometric methods. The oldest dates are approximately 3.3 mya for hominid specimens (perhaps *A. africanus*) discovered in the late 1990s at Sterkfontein. Most of the samples of this species are between about 3.0 and perhaps 2.4 million years old.

A. africanus and *A. afarensis* compared

A. africanus resembles *A. afarensis* in many respects but also shares unique features with early *Homo* that are not present in the more primitive *A. afarensis*. These include reduced facial projection (although there is considerable variation within *A. africanus*). It also possesses unique specializations not seen in *A. afarensis* or in early *Homo* that are related to powerful chewing, such as expansion of the cheek teeth, increased jaw size, and changes to the skull to accommodate the forces generated. Compared with those of *A. afarensis*, the lower limbs of *A. africanus* appear to be smaller and the upper limbs larger. Males weighed approximately 41 kilograms (90 pounds) and stood 138 centimetres (4 feet 6 inches) tall. Females weighed about 30 kilograms (66 pounds) and stood 115 centimetres (3 feet 9 inches) tall. Brain size averages 448 cubic centimetres (27 cubic inches), closer to modern chimpanzees (395 cc) than to humans (1,350 cc).

PARANTHROPUS AETHIOPICUS

Paranthropus aethiopicus (2.7–2.3 mya) is the earliest of the so-called "robust" australopiths, a group that also includes *P. robustus* and *P. boisei* (described below). *Robust* refers to exaggerated features of the skull, but it does not imply robusticity in any other aspects of the body. The expansion of cheek teeth and supporting structures for grinding hard, tough food continues in later australopiths.

Further specializations for strong chewing occur in *P. aethiopicus* fossils from the Omo remains, discovered in the Omo River valley in southern Ethiopia, and in remains found on the western shore of Lake Turkana in northern Kenya. Most of the remains are in the form of isolated teeth and fragmentary jaws, but one remarkably complete skull from 2.5 mya (the "Black Skull") was recovered from West Turkana. In features related to chewing, *P. aethiopicus* resembles the East African *P. boisei* (2.2–1.3 mya) in having enormous molars and premolars, a thick palate and jaws, and projecting cheekbones. In other respects, however, *P. aethiopicus* shares the primitive morphology of *A. afarensis* in having a projecting lower face, a large rear portion for attachment of the jaw muscle (temporalis), and flat cranial bones, among other features. Its resemblance to *P. boisei* may be attributable to their similar diets rather than to a closely shared descent.

PARANTHROPUS ROBUSTUS AND *P. BOISEI*

Paranthropus robustus and *P. boisei* are also referred to as "robust" australopiths. Some paleoanthropologists classify these two species as *Australopithecus*, but they appear to be closely related and distinctly different from other australopiths. In addition to a well-developed skull crest for the attachment of chewing muscles, other specializations for strong chewing include huge cheek teeth, massive jaws, and powerfully built cheekbones that project forward. These features make their skulls look very unlike those of modern humans.

Robert Broom recovered the first specimen of a robust australopith in 1938 from the South African cave site of Kromdraai. He gave it the name *Paranthropus robustus* and noted its hominid features as well as its exaggerated chewing apparatus. Between 1948 and 1952 similar fossils were unearthed from Swartkrans, South Africa, which proved to be another of the richest sources of early hominids. A third source of *P. robustus* is the limestone cave of Drimolen, South Africa, where a team began collecting in 1992. All three sites are located within a few kilometres of one another in a valley about 30 kilometres (18 miles) west of Johannesburg. As with the remains of *A. africanus*, the only method of dating the *P. robustus* remains is via biostratigraphy, which indicates that *P. robustus* dates from about 1.8–1.5 mya. Specimens attributed to *Homo* also occur in the same deposits, but these are much rarer.

Broom's choice of the name *Paranthropus* (meaning "to the side of humans") reflects his view that this genus was not directly ancestral to later hominids, and it has long been viewed as a distant side branch on the human evolutionary tree. Its specializations for strong chewing certainly make it appear bizarre. The choice of the name *robustus* referred to its heavily built jaws, teeth, and supporting structures. Its body was relatively petite, however, with males weighing about 40 kilograms (88 pounds) and females about 32 kilograms (70 pounds). Its brain size is 523 cubic centimetres, which is both absolutely and relatively larger than that of the earlier South African australopith, *A. africanus*, with its average brain of 448 cubic centimetres.



Figure 21: *Paranthropus boisei* (OH 5, replica with reconstruction), found at Olduvai Gorge, Tanzania.
Skulls Unlimited International, Inc.

Mary Leakey discovers OH 5

The spectacular 1959 discovery of a nearly complete skull (OH 5) by Mary Leakey at Olduvai Gorge, Tanzania, first revealed the presence of a robust australopith in East Africa (see Figure 21). It shares with its South African cousin the combination of chewing specializations and *Homo*-like evolutionary novelties not present in earlier australopiths. For this reason it is included in the same genus as the South African *Paranthropus*, but it is different enough to warrant its own species name, *P. boisei*. It dates to 2.2–1.3 mya, and in that interval it is the most abundant hominid species known, with specimens numbering in the hundreds. It has the greatest development of features related to chewing (mastication), possessing truly massive cheek teeth and jaws. It lived at the same time as species of early *Homo*, but there is some evidence that *Homo* and *P. boisei* preferred different habitats. Despite the enormity of its chewing apparatus, it had a relatively small body, with males weighing about 49 kilograms (108 pounds) and females 34 kilograms (75 pounds). *P. robustus* and *P. boisei* fossils are found with mammals that are usually associated with dry grassland habitats.

RELATIONSHIP TO *HOMO*

Quality of the fossil record. Despite the fact that hominids were a rare and insignificant part of the mammalian fauna before about 40,000 years ago, Africans (anthropologists and nonanthropologists alike) and their internation-

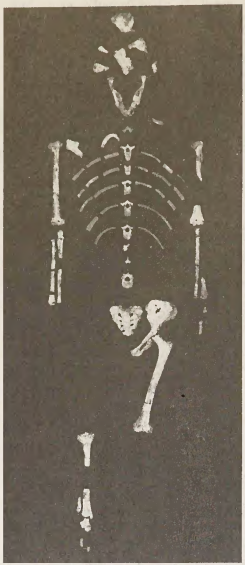

Figure 22: *Australopithecus afarensis* skeleton ("Lucy," AL 288-1), found at Hadar, Ethiopia.
Cleveland Museum of Natural History

al colleagues have had phenomenal success in exposing a rich fossil record of australopiths. However, abundant as the fossils are, there are still limitations. For example, the evidence is restricted geographically. The first two-thirds of the fossil record comes almost entirely from sites in the East African Rift Valley and from limestone caves in South Africa. The exceptions are *Sahelanthropus tchadensis* and the jaw fragment from Baḥr el-Ghazāl in Chad, which call attention to the strong likelihood that other hominids lived throughout tropical and subtropical Africa but left fossils that have not yet been found.

Even with comparatively rich samples of species such as *A. afarensis* and *A. africanus*, most of the specimens are very fragmentary, and even partial skeletons are rare. The *A. afarensis* skeleton "Lucy" (see Figure 22) stands almost alone in its completeness for the first several million years, joined only by a skeleton from Sterkfontein. The rarity of skeletons makes the reconstruction of body size and shape dependent on many assumptions, which can be subject to interpretation. Another limitation to understanding arises from homoplasy, the appearance of similarities in separate evolutionary lineages. Homoplasy was common in hominid evolution. Various evolutionary novelties appear in the record over time, but many must have evolved independently—for example, extreme expansion of the cheek teeth and all the chewing structures of "robust" australopith species and, to a lesser extent, of *A. afarensis*, *A. africanus*, and *A. garhi*. Extreme development of such traits links the robust australopiths—*P. aethiopicus*, *P. boisei*, and *P. robustus*—into a separate lineage.

Homoplasy

A related difficulty is the limited understanding of character transformations. Are all traits truly independent evolutionary novelties, or are some of them part of complexes that change together? Jaw size and tooth size, for example, are not independent, and flexion of the base of the skull and being flat-faced are generally correlated. Taxonomic grouping based on shared evolutionary novelties (cladistic analysis) brings these correlations into focus. Research on developmental biology will provide important clues about the evolutionary independence of characteristics.

The limitations outlined above are important, but they must be balanced by appreciation of successes. These successes can be organized in many ways. For example, the accumulation of evolutionary novelties can be followed over time. This approach appears obvious, but it has its subtlety, acknowledging that any known sample of fossils represents a species that was successful at the time but was not necessarily the direct ancestor of later species. Speciation probably occurred in small, isolated, peripheral populations that the fossil record has not sampled. What we collect is what was successful at the time. Therefore, we might expect to find many unique characteristics (autapomorphies) of fossil species that exclude them from direct ancestry but that also provide keys to reconstructing the common ancestor of later species.

Subtlety of the fossil record

From this point of view, the fossil record is superb. One can follow the hominid lineage step by step as the accumulation of humanlike characteristics. Oddities may be autapomorphies of a particular species, but they do not necessarily exclude the possibility that it and subsequent species shared a common ancestor. It is important to realize that this accumulation has no predetermined direction. We look back on history and see patterns, but these patterns were not established in advance, as evolution has no predetermined direction.

Changes in anatomy. The hominid fossil record does not include a truly intermediate form between an apelike and a humanlike body. *Australopithecus* retains many primitive apelike traits, but, unlike any ape, it is fundamentally reorganized and highly specialized for walking upright. This state of development required a profound alteration in the genetic template to produce short pelvic blades, a forward-pointing big toe (adducted hallux), and other bipedal traits. The precise sequence of these transformations may in fact never be known from the fossil record, because different parts of the bipedal body may have changed at different rates. For example, the pelvic blades may have shortened before the big toe straightened. Such is the case with the extinct and distinctly nonhuman ape *Oreopithecus*, which appears to have had reduced pelvic blades but retained a divergent big toe.

Regardless of when or how traits arose, bipedalism is the diagnostic criterion for the evolutionary departure of the human family from apes. Bipedal behaviour, however, would have arisen before any fossil evidence of adaptations to it. Thus, the very first hominids most likely had rather apelike bodies without the adaptations for bipedalism that later became the hallmark of the human lineage. These African and possibly European species dating to the late Miocene Epoch (11.2–5.3 million years ago) came, in Charles Darwin's words, "to live somewhat less on trees and more on the ground," owing to "a change in its manner of procuring subsistence, or to a change in the conditions of its native country."

Although Darwin and his contemporaries predicted much of what the human fossil record would eventually reveal, no one anticipated the discovery of hominids with massive jaws. African apes and modern humans have small cheek teeth relative to body size. Australopiths, on the other hand, had huge molars and premolars with concomitantly gigantic jaws, buttressed cheekbones and face bones, and large areas on the skull for the attachment of chewing muscles.

There appear to be two major structural shifts in the evolution of the human body. The first was the transition to bipedalism that is documented in *A. anamensis*, *A. afarensis*, *A. africanus*, and *A. garhi*, which span a time frame from 4.2 to 2.5 mya. The limbs and torsos among these species are difficult to assess because of the incompleteness of the fossil record. All share features with *Homo*, but only *A. afarensis* and *A. africanus* are complete enough to make detailed comparisons. These two species share a similar mixture of apelike, humanlike, and unique features in their wrists, hips, and knees. They apparently differ in limb

Australopithecus as transitional to *Homo*

joint sizes, however, with *A. africanus* appearing to be more apelike even though it lived later in time and had a more *Homo*-like skull and teeth. Both species appear to share a combination of specialized bipedal traits but are not exactly like modern humans in that they possess upper limb features associated with climbing.

The second major change in evolution appears at about 1.9 mya with the appearance of hips that are uniquely *Homo*. Long femurs and relatively enlarged hip joints mark a significant change in locomotion that is related, perhaps, to long-distance, efficient striding more like that seen in modern *H. sapiens*. The discovery of *A. garhi* reveals the complexity of tracing evolution of limb proportions in that it had a humanlike femur-to-upper-arm ratio yet a long, apelike forearm.

There are opposing interpretations of the primitive body traits retained in the early species of *Australopithecus*. One view emphasizes the bipedal specializations, whereas the other calls attention to the many primitive skull characteristics. Even so, both camps agree that all species of *Australopithecus* were bipedal and thus did not climb like apes. Australopiths did, however, retain features associated with tree-dwelling for at least a million years. Their different hip architecture implies some difference from modern humans in gait and climbing ability. The divergence between *Australopithecus* and later-appearing *Homo* became clearer with the discoveries of lower-body fossils associated with *Homo erectus*, particularly the "Strapping Youth," also called "Turkana Boy," found at Nariokotome, Kenya, in 1984. The striking difference between the pelvis and femur of *Australopithecus* and those of *Homo* probably registers a major shift in adaptation between the two groups. From this perspective, *Australopithecus* appears to have had the hands free for carrying but was adapted only to traveling short distances. It likely had a healthy appreciation of trees for safety, feeding, and sleeping. The longer femur and more humanlike pelvis that appear by 1.9 mya in *Homo* mark the beginning of an important change.

"Turkana Boy" discovered

Not only were there numerous species of human predecessors long ago, but many of these overlapped in time and space (see Figures 3 and 17). Habitats favourable for hominid occupation undoubtedly appeared and disappeared throughout much of Africa over and over again with the drastic fluctuations in tropical climates that occurred during the Pliocene and Pleistocene epochs. More species presumably await discovery, because there were probably many evolutionary experiments in these varied and changing habitats. Although the current sample of fossil hominids leads some to the impression that there were only a few hominid lineages, it is far more likely that the human family tree will turn out to be quite "bushy." Species names may need to multiply to accommodate the diversity, although a balance needs to be maintained between excessively splitting groups apart and lumping them together.

Evidence regarding the relationship of *Australopithecus* to the origin of the genus *Homo* may appear to conflict, but, from the perspective of accumulated shared traits, the fossil record is less perplexing. Put simply, brains expand and cheek teeth shrink. In *H. habilis* (2.0–1.5 mya) the body appears to remain like that of *Australopithecus*—small with relatively large upper limbs and small lower limbs. If the lower limb fossils found with the skulls and teeth of a 1.9-million-year-old specimen of *H. rudolfensis* also belong to this species, then the more humanlike body proportions and hip architecture first appear in this species just after 2 mya. Both *H. habilis* and *H. rudolfensis* are transitional, with some primitive and some derived characteristics of later *Homo* species. Other skeletal remains are critical here because body size appears to be very different. *H. habilis* was very small (35 kilograms [77 pounds]), and *H. rudolfensis* was large (55 kilograms [121 pounds]). Scaling cheek-tooth size to body weight shows that they both had reversed the trend of ever-increasing cheek-tooth size. Relative brain size expanded, especially in *H. habilis*. Brain size expanded further with the appearance of *H. erectus* by at least 1.8 mya, but body size also increased, so that relative brain size apparently was not so dramatically expanded. The early African form of *H. erectus* is often referred to as *H. ergaster* to contrast it with the well-known Asian *H. erectus*. Body size and especially hind limb length reach modern proportions in this species. Other traits *Australopithecus* has in common with later *Homo* include a further reduction in facial projection as well as other features, including reduction in the size of the cheek teeth. Brains then continue to expand and cheek teeth become progressively smaller through the evolution of the genus *Homo*.

(H.Mc.)

Homo habilis

Homo habilis is the most ancient representative of the human genus (*Homo*). This species inhabited parts of sub-Saharan Africa from perhaps 2 to 1.5 mya. In 1959 and 1960 the first fossils were discovered at Olduvai Gorge in northern Tanzania. This discovery was a turning point in the science of paleoanthropology because the oldest previously known human fossils were Asian specimens of *Homo erectus*. Many features of *H. habilis* appear to be intermediate in terms of evolutionary development between the relatively primitive *Australopithecus* and the more-advanced *Homo* species (see Figure 1).

The first *H. habilis* remains found at Olduvai consist of several teeth and a lower jaw associated with fragments of a cranium and some hand bones. As more specimens were unearthed at locations such as Koobi Fora in northern Kenya, researchers began to realize that these hominids were anatomically different from *Australopithecus*, a genus of more-apelike creatures whose remains had been found at many African sites. Formal announcement of the discoveries was made in 1964 by anthropologists Louis S.B. Leakey, Phillip Tobias, and John Napier. As justification for designating their new creature *Homo* rather than *Australopithecus*, they described the increased cranial capacity and comparatively smaller molar and premolar teeth of the fossils, a humanlike foot, and hand bones that suggested an ability to manipulate objects with precision—hence the species name *Homo habilis*, meaning "handy man" or "able man." Furthermore, simple stone tools were found along with the fossils. All these characteristics foreshadow the anatomy and behaviour of *H. erectus* and later humans, making *H. habilis* extremely important, even though there are few remnants of it.

The "handy man"

FOSSIL EVIDENCE

Apart from the original discovery of the jaw, cranial, and hand bones from a juvenile individual called Olduvai Hominid 7 (OH 7; see Figure 23), additional fossils from Olduvai have been ascribed to *H. habilis*. Pieces of another thin-walled cranium along with upper and lower jaws



Figure 23: Lower jaw of OH 7, the first individual to be given the name *Homo habilis*, found at Olduvai Gorge, Tanzania.

G. Philip Rightmire



Figure 24: *Homo habilis* skull (OH 24, replica with reconstruction), found at Olduvai Gorge, Tanzania.
Skulls Unlimited International, Inc.

and teeth came to light in 1963. Just a month later a third skull was found, but these bones had been trampled by cattle after being washed into a gully. Some of the teeth survived, but the cranium was broken into many small fragments; only the top of the braincase, or vault, has been pieced back together. These two skulls are called OH 13 and OH 16.

Since 1964 more material has been discovered, not only at Olduvai but at other African localities as well. One intriguing specimen is OH 24 (see Figure 24). This cranium is more complete than others from Olduvai. Because some of the bones are crushed and distorted, however, the face and braincase are warped. OH 24 may differ from *Australopithecus* in brain size and dental characteristics, but it resembles the australopiths of southern Africa in other features, such as the shape of the face. Complete agreement concerning its significance has not been reached, partly because the fossil is damaged.

Important discoveries made in the Koobi Fora region of northern Kenya include a controversial skull called KNM-ER 1470 (Kenya National Museum–East Rudolf), which resembles both *Australopithecus* and *Homo* (see Figure 25). As in the case of OH 16, this specimen had been broken into many fragments, which could be collected only after extensive sieving of the deposits. Some of the pieces were then fitted into the reconstruction of a face and much of a large vault. Brain volume can be measured rather accurately and is about 750 cubic centimetres. This evidence prompted some paleoanthropologists to describe ER 1470 as one of the most ancient undoubted representatives of the genus *Homo* because some other features of the braincase are also *Homo*-like. At the same time, it is apparent that the facial skeleton is relatively large and flattened in its lower parts. In this respect, the Koobi Fora specimen resembles *Australopithecus* anatomically.

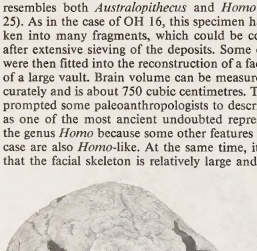

Figure 25: *Homo habilis* skull (KNM-ER 1470, replica with reconstruction), found at Koobi Fora, Kenya. Some paleoanthropologists instead classify this specimen as *Homo rudolfensis*.
Skulls Unlimited International, Inc.

Among other key finds from the Koobi Fora region are KNM-ER 1813 and KNM-ER 1805. The former, which is most of a cranium, is smaller than ER 1470 and resembles OH 13 in many details, including tooth size and morphology. The latter skull exhibits some peculiar features. Although the braincase of ER 1805 is close to 600 cubic centimetres in volume and is thus expanded moderately beyond the size expected in *Australopithecus*, a bony crest runs along the top of the skull. This sagittal crest is coupled with another prominent crest oriented across the rear of the skull. These ridges indicate that the chewing muscles and neck muscles were powerfully developed. A similar if more exaggerated pattern of cresting appears in the so-called robust australopiths but not in *Homo*. Other features of ER 1805, however, are *Homo*-like. As a result, there has been disagreement among anatomists regarding the hominid species to which this individual should be assigned. Despite its anomalies, ER 1805 is often discussed along with other specimens grouped as *H. habilis*.

The enigmatic ER 1805

Several mandibles resembling that of OH 7 have been recovered from the Koobi Fora area, and teeth that may belong to *H. habilis* have been found farther to the north, in the Omo River valley of Ethiopia. Some additional material, including a badly broken cranium, are known from the cave at Swartkrans in South Africa. At Swartkrans the fossils are mixed with many other bones of robust australopiths. An early species of *Homo* may also be present at Sterkfontein, not far from Swartkrans. Here again the remains are fragmentary and not particularly informative.

A more valuable discovery was reported from Olduvai Gorge in 1986. A jaw with teeth and skull fragments as well as pieces of a right arm and both legs were found. The bones seem to represent one individual, called OH 62. Although the skull is shattered, enough of the face is preserved to suggest similarities to early *Homo*. The find is especially important because of the limbs, which show that OH 62 was a very small hominid. The arm is long relative to the leg, resulting in body proportions that differ dramatically from those of more modern hominids.

BODY STRUCTURE

Olduvai and Koobi Fora fossils have allowed researchers to make some determinations about the anatomy of early humans. It is clear that the braincase of *H. habilis* is larger than that of *Australopithecus*. The original finds from Olduvai Gorge include two sizable bones from the skull of OH 7. An incomplete brain cast was molded by putting the bones together to form a partial cranium. This cast has been used to estimate a total brain volume of about 680 cubic centimetres. A brain cast from ER 1470, which has a more complete cranium, can be measured directly; its volume is about 775 cubic centimetres. One or two additional fragmentary skulls appear to be about the same size as that of ER 1470. Others—such as ER 1813, which has a cranial capacity of only about 510 cubic centimetres—are much smaller. Thus, brain sizes ranging from slightly more than 500 to nearly 800 cubic centimetres seem to characterize *H. habilis*.

The skulls by and large have thin walls and are rounded, rather than low and flattened; they do not have the heavy crests and projecting browridges characteristic of later *H. erectus*. The underside of the cranium is shortened from the back of the palate to the rear of the skull, as in all later *Homo* species. This is an important contrast to the so-called gracile australopiths, in which the cranial base is relatively narrow and elongated.

The face of *Homo habilis*

The facial bones of several specimens are at least partly preserved, and facial proportions vary considerably. One of the Olduvai hominids, OH 24 (see Figure 24), seems anatomically similar to *Australopithecus* in having prominent cheekbones and a flat nasal region. This gives the central region of the face a depressed, or "dished," appearance, and the upper part of the nasal profile is obscured by the cheek when the specimen is viewed from the side. Such hollowing of the face is characteristic of some South African australopiths but is not seen in later *Homo*. The facial skeleton of ER 1470 is large relative to the braincase,

and it shows flattening below the nose—*Australopithecus*-like features. The walls of the nasal opening, however, are slightly everted, and there is at least an indication that the nose stands out in more relief than would be expected in australopiths. The face of ER 1813 is even more modern.

The front teeth of *H. habilis* are not much different in size from those of *Australopithecus*, but the premolar and molar crowns—particularly in the lower jaw—are narrower. The jaw itself may be quite heavily constructed like that of gracile australopiths. This is the case for OH 7 and also for at least one specimen from Koobi Fora. Other jaws are smaller but still robust in the sense of being thick relative to height. For example, the mandible of OH 13 is similar in many respects to that of *H. erectus*, and this individual might have been called *H. erectus* if its jaw had not been found along with small, thin vault bones.

Only a few other skeletal parts have been discovered. Some limb bones from Olduvai and Koobi Fora have been grouped tentatively with *H. habilis* on the basis of general anatomic similarity to later humans. These fossils, however, are not associated with any teeth or skulls, and it is probably not appropriate to use them as the basis for describing early *Homo*. One individual for which body parts are more fully represented is OH 62. Arm and leg bones of OH 62 are fragmentary, but the arm is relatively long. The skeleton may be similar in its proportions to small australopiths. OH 62 probably walked on two legs as efficiently as other early hominids, but this diminutive individual was unlike later humans in many respects.

Another important specimen is the immature hand of OH 7. These bones, found with skull bones, are still apelike in some aspects, but it is almost certain that the individual from which they came had dexterous hands. Stone artifacts and early *Homo* fossils have been found at Olduvai and other sites. These tools are called the Oldowan industry, and, though they are crude, they indicate that *H. habilis* could shape stone.

BEHAVIORAL INFERENCES

The stone tools and unused waste materials (mainly crude chopping tools and sharp flakes) left by *H. habilis* provide important clues about the behaviour of these early humans. Olduvai Gorge has been a rich source of Oldowan tools, and the tools are often found with animal fossils. Originally, the occurrence of artifacts with bones was interpreted to mean that *H. habilis* hunted animals and brought the carcasses to where it lived for butchering, but it is now known that the situation was more complicated. Assemblages such as those found at Olduvai can be created through various means, not all of which are related to hominid activities. Olduvai *H. habilis* certainly used animal products, however. With the aid of a scanning electron microscope, it has been shown that cut marks on some of the bones must have been made by stone tools, but this does not prove that animals were hunted. Analysis of Olduvai animal fossils also shows that some marks were made by either rodent or carnivore teeth, the indication being that at least some of the animals were killed by nonhominid predators. In all likelihood, the hominids at Olduvai could obtain larger carcasses only after the animals had been killed and partially eaten by other predators. *H. habilis* may have hunted small prey, such as antelope, but definitely was a scavenger.

It is debatable whether or not the Olduvai sites were home bases. Nothing recovered indicates that people resided where the animal bones accumulated. Such areas were presumably dangerous since they undoubtedly attracted numerous predators. These sites may have been caches of stone tools and raw materials that were established in areas convenient for rapid processing of animal parts. Therefore, where the hominids lived or whether their social structure was prototypical of later hunter-gatherers remains unknown, although *H. habilis* must have engaged in cultural activities.

The question of language

Whether or not early *Homo* had acquired language is another fundamental question, and the indirect evidence on this issue has been variously interpreted. It is the belief of some anatomists that endocranial casts of *H. habilis* fossils indicate that the regions associated with speech in modern humans are enlarged. Others disagree with this assessment, particularly since the number of braincases preserved well enough to make detailed casts is small. Anthropologists have also based their interpretations on the archaeological record. According to some, the crude Oldowan artifacts indicate the ability to use language. Critics of this view assert that the Oldowan industry represents only opportunistic stonework. They argue that, because the later Acheulean tools of *H. erectus* are more carefully formed and are often highly symmetrical, this later hominid was the first to use symbols and language. One of the problems with this theory is that no clear link between technological and linguistic behaviour has been established—even the more sophisticated tools could have been made by nonspeaking hominids. Thus, it is not certain when *Homo* developed the linguistic skills that characterize modern humans.

DATING THE FOSSILS

Several approaches have been used to date *H. habilis* fossils from Olduvai, and a reasonably accurate timescale for Olduvai has been developed. The oldest remains, including OH 24, are from about 1.85 mya. Others such as OH 7 and OH 62 are not quite so ancient. The youngest Olduvai skull that is representative of early *Homo* is OH 13. No radiometric date for it is available, but other dating methods estimate it to be about 1.5 million years old.

In the Koobi Fora region a number of important fossils have been located near a level of volcanic ash that also contains stone tools. This ash bed was dated to about 2.6 mya. When ER 1470 was discovered several metres below this layer in 1972, it was thought that the newfound cranium must document *Homo* from a time well before the Olduvai deposits had accumulated. This assumption was soon questioned on the basis of other evidence, however, and before 1980 it was clear that the age had been overestimated. A series of radiometric determinations done subsequently has yielded a date of 1.88 mya. The ER 1470 skull and other *H. habilis* specimens recovered below this ash layer, therefore, must be close to two million years old. Evidence from East Africa thus suggests that *H. habilis* lived for a half-million years or so before giving way to later *Homo* species.

EVOLUTIONARY IMPLICATIONS

The general interpretation of the fossil evidence is that *H. habilis* is not only substantially different from *Australopithecus* but that it represents the beginning of the trends characterizing human evolutionary history, particularly expansion of the brain. Some specimens clearly have a larger cranial capacity than that of *Australopithecus*, and the capacity increases progressively afterward with *H. erectus*, archaic *H. sapiens*, and modern humans (see Figure 12). *H. habilis* is also thought to exhibit the origins of other trends such as smaller teeth and changes in facial structure, especially the nasal region.

Interpreting the evidence

The theory that *H. habilis* is intermediate between relatively primitive *Australopithecus* and more advanced *Homo* appears to be generally accurate, but several aspects of this view can be challenged. Although there are not many *H. habilis* fossils, it is becoming clear that there are anatomic differences among the East African assemblages. Some of the newer discoveries have confirmed the expectation that early *Homo* craniums should be relatively large, with the rear of the skull being rounded and its base shortened. Other fossils have proved less easy to assign to *H. habilis*, and there has been controversy over their interpretation. Some braincases are considerably smaller, and it is frequently suggested that this variation is one of the differences between males and females (sexual dimorphism), the larger skulls being ascribed to males. But there are differences in shape as well as size, and several of the smaller skulls depart from the morphology of large-brained *H. habilis* in ways that are not obviously related to sex. There are also facial similarities between some specimens and *Australopithecus*. Thus, there is the possibility that two different species rather than one sexually dimorphic group are actually represented by the fossils.

Classifying the various specimens separately means that

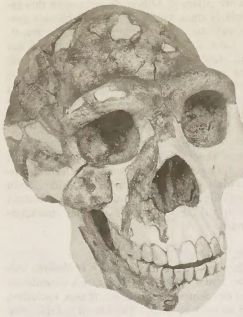

Figure 26: *Homo erectus* skull of "Peking man" (replica with reconstruction), found at Chou-k'ou-tien.
Skulls Unlimited International, Inc.

each must be fitted into a scheme of hominid descent, or phylogeny. One interpretation assigns specimens with smaller craniums to a gracile species of *Australopithecus*. According to this scenario, only the larger skulls represent early *Homo* evolution. Others, questioning the notion that all species of *Homo* proceed along a simple linear progression, believe that early human populations were more diverse than has been recognized; although these researchers recognize two separate species, they prefer to lump both in the genus *Homo*. In this view, two species may have lived contemporaneously 2.0–1.5 mya. Only one could be the direct ancestor of *H. erectus*, and so perhaps it was the large-brained form that evolved further, while the smaller hominid became extinct. (G.P.Ri.)

Homo erectus

Its name Latin for "upright man," this extinct species of the human genus was perhaps an ancestor of modern humans (*H. sapiens*; see Figure 1). *Homo erectus* most likely originated in Africa, though Eurasia cannot be ruled out. Regardless of where it first evolved, the species seems to have dispersed quickly, starting about 1.7 mya near the beginning of the Pleistocene Epoch, moving through the African tropics, Europe, South Asia, and Southeast Asia. This history has been recorded directly if imprecisely by many sites that have yielded fossil remains of *H. erectus*. At other localities, broken animal bones and stone tools have indicated the presence of the species, though there are no traces of the people themselves. *Homo erectus* was a human of medium stature that walked upright. The braincase was low, the forehead was receded, and the nose, jaws, and palate were wide. The brain was smaller and the teeth larger than in modern humans. *Homo erectus* seems to have flourished until some 200,000 years ago (200 kya) or perhaps later before giving way to other humans including *H. sapiens*.

FOSSIL EVIDENCE

Homo erectus discovered

The earliest finds. The first fossils attributed to *H. erectus* were discovered by a Dutch army surgeon, Eugène Dubois, who began his search for ancient human bones on the island of Java (now part of Indonesia) in 1890. Dubois found his first specimen in the same year, and in 1891 a well-preserved skullcap was unearthed at Trinil on the Solo River (see Figure 27). Considering its prominent browridges, retreating forehead, and angled rear skull, Dubois concluded that the Trinil cranium showed anatomic features intermediate between those of humans (as they were then understood) and those of apes. Several years later, near where the skull was discovered, he found a remarkably complete and modern-looking femur (thighbone). Since this bone was so similar to a modern human femur, Dubois decided that the individual to which it belonged must have walked erect. He adopted the name *Pithecanthropus* (coined earlier by the German zoologist Ernst Haeckel) and called his discoveries *Pithecanthropus erectus* ("upright ape-man"), but the colloquial term became "Java man." Only a few other limb fragments turned up in the Trinil excavations, and it would be some three decades before more substantial evidence appeared. Most paleontologists now regard all of this material as *H. erectus*, and the name *Pithecanthropus* has been dropped.

Other Asian fossils. Subsequent discoveries continued to establish a case for this new and separate species of fossil hominid. At first these discoveries were centred largely in Asia. For example, similar fossils were found during the early 20th century at several different locations in Java: Kedung Brubus, Modjokerto (Mojokerto), Sangiran (see Figure 28), Ngandong (Solo), Sambungmatjan (Sambungmacan), and Ngawi. Another series of finds was made in China beginning in the 1920s, especially in the caves and fissures of Chou-k'ou-tien (Zhoukoudian), near Peking (Beijing). Remains found at Chou-k'ou-tien by Davidson Black became popularly known as Peking man (see Figure 26); virtually all of these remains were subsequently lost by 1941 during the Sino-Japanese War (1937–45), though casts of them still exist. Newer discoveries have since been made in the Chou-k'ou-tien caves and at four other Chinese sites: Kung-wang-ling (Gongwangling) and Ch'en-chia-wo (Chenjiawo) in the Lan-t'ien (Lantian) district of Shensi province, Hulu Cave near Nanking, and Ho-hsien (Hexian) in Anhwei province (see Figure 27). By the end of World War II the pattern of early discovery had given rise to the idea that *H. erectus* was a peculiarly Asian ex-

Peking man

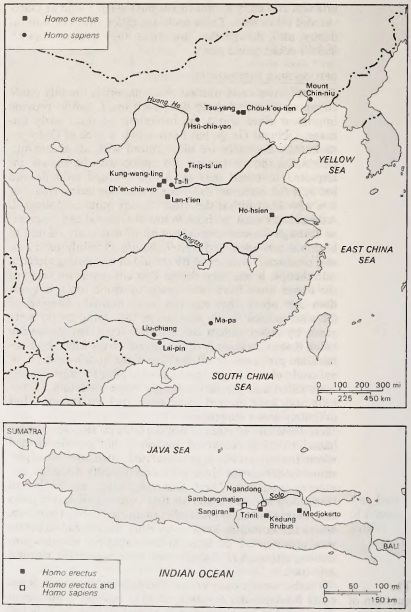

Figure 27: Sites of hominid fossil finds in (top) China and (bottom) Java.
Encyclopædia Britannica, Inc.



Figure 28: *Homo erectus* skull (Sangiran 17, replica), found at Sangiran, Java, Indonesia.
Skulls Unlimited International, Inc.

pression of early humans. Subsequent discoveries in Africa changed this view, and by the end of the 20th century it was confirmed that Europe also harboured *H. erectus*.

African fossils. In North Africa in 1954–55, excavations at Ternifine (Tighenif), east of Mascara, Algeria, yielded remains dating to approximately 700,000 years ago whose nearest affinities seemed to be with the Chinese form of *H. erectus*. Other Moroccan hominid fragments from this region—parts of a skull found in 1933 near Rabat and jaws and teeth from Sīdī ʿAbd ar-Raḥmān (Sidi Abderrahman) in Morocco—show features reminiscent of *H. erectus*, though they are rather more advanced in structure than those of Ternifine and Asia. Another fossil likened to *H. erectus* is a 400,000-year-old cranium found in 1971 at Salé, Morocco. Although nearly all of the face and part of the forehead have broken away, it is an important specimen.

OH 9 discovered by Louis Leakey

Some of the more convincing evidence for the existence of *H. erectus* in Africa came with the discovery in 1960 of a partial braincase at Olduvai Gorge in Tanzania. This fossil, catalogued as OH 9, was excavated by Louis S.B. Leakey and is probably about 1.2 million years old. Olduvai Gorge has since yielded additional cranial remains, jaws, and limb bones of *H. erectus*. Much of this material is fragmentary, but gaps in our knowledge of East African *H. erectus* have been filled to some extent through finds made by Louis Leakey's son, Richard Leakey. Since 1970 a number of important fossils have been unearthed at localities on the eastern shore of Lake Turkana (Lake Rudolf) in northwestern Kenya, now commonly referred to as the Koobi Fora sites. The fossils recovered there may be about 1.7 million years old, based on radiometric dating of the associated volcanic material. Included in these assemblages are the remains of *Australopithecus* and probably some representatives of early *Homo*. Of several specimens that are clearly *Homo*, one cranium (KNM-ER 3733) is quite complete and well-preserved (see Figure 29). Dated to 1.75 mya, it is likely to be one of the most ancient *H. erectus* fossils discovered in Africa. It and other specimens from Koobi Fora are considered by some paleontologists to be a separate species they call *H. ergaster*. Other significant finds in this area include a partially intact skeleton (KNM-ER 1808), although it comes from a diseased individual. A more complete skeleton named "Turkana Boy" (KNM-WT 15000) was found nearby at Nariokotome, a site on the northwestern shore of Lake Turkana. The remains of this juvenile male have provided much information about growth, development, and body proportions of an early member of the species.

"Turkana Boy"

European fossils. Although it has been recognized for some time that Africa as well as Asia was peopled by at least one form of *H. erectus*, the situation in Europe is less clear. One of the oldest European hominid fossils is an isolated mandible (lower jawbone) with teeth, found in 1907 in a sandpit just north of Mauer, Germany, near Heidelberg. Dating to about 500,000 years ago, it has been given a variety of names over the years, but its exact relationship to other fossils remains uncertain, partly because no associated cranium was found. Some investigators have come to regard the Mauer mandible as representing *H. erectus*. Although its age is perhaps comparable to that of the older Chou-k'ou-tien hominids in China, this European specimen shows more modern structural features than do the Asian and African jaws of *H. erectus*. The exact significance of these features in the Mauer jaw is still being debated, and some consider it a separate species (*H. heidelbergensis*) that is slightly more advanced in its anatomy than the African and Asian populations. Another fossil that may tentatively be grouped with the Mauer mandible is a lower leg bone (tibia) found in 1993 during excavations at Boxgrove, West Sussex, England.

More convincing evidence for the presence of *H. erectus* in Europe has come from Ceprano in central Italy, where a skull lacking its face was found in 1994. Clay deposits surrounding it contain no volcanic material that is directly datable, but the fossil is probably somewhat older than the Mauer mandible. The Ceprano individual displays the heavy continuous brow, low braincase, angled rear skull, and thick cranial bones that are characteristic of *H. erectus*.

Other important fossils have been recovered in the southern Caucasus region of Georgia. Excavations at the medieval village of Dmanisi revealed a jaw with a full set of teeth in 1991. Found along with animal bones and crude stone tools, this specimen has been likened to *H. erectus*, and it is much more ancient than the remains from Mauer or Ceprano. In 1999 two more craniums were reported from the same site. These well-preserved individuals confirm the presence of *H. erectus* at the gates to Europe and seem to resemble the fossils from the Koobi Fora sites in Kenya. Dated to 1.7 mya, the Dmanisi hominids are among the oldest known outside of Africa, and they bear directly on the question of how *H. erectus* evolved and dispersed across the Old World.

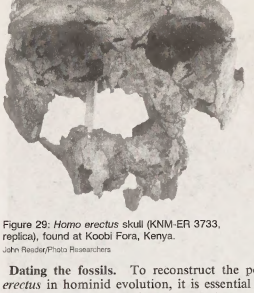

Figure 29: *Homo erectus* skull (KNM-ER 3733, replica), found at Koobi Fora, Kenya.
John Reader/Photo Researchers

Dating the fossils. To reconstruct the position of *H. erectus* in hominid evolution, it is essential to define the place of this species in time, and modern paleoanthropologists have at their disposal a variety of techniques that permit them to do so with great precision. Potassium-argon dating, for instance, can provide the age of a specimen by clocking the rate at which radioactive isotopes of these elements have decayed. When radiometric methods cannot be applied, investigators may still ascribe a relative age to a fossil by relating it to the other contents of the deposit in which it was found.

Homo erectus exists for one million years

Such lines of evidence have led to the tentative conclusion that *H. erectus* flourished over a long interval of Pleistocene time. The fossils recovered at Koobi Fora are from about 1.7 mya, and OH 9 from Olduvai is probably 1.2 million years old. The specimens from Sangiran and Mojdokerto in Java may approach the age of the Koobi Fora

skeletons, and one from the Lan-t'ien localities in China is roughly contemporary with OH 9. The youngest hominids generally accepted as *H. erectus* are from Ternifine in Algeria (800–600 kya), Chou-k'ou-tien in China (500–250 kya), and Sambungmatjan and Ngandong (Solo) in Java (perhaps less than 250 kya).

For the most part, fossils older than 1.7 million years are the remains of *H. habilis* and *H. rudolfensis*. These species are also known from Olduvai Gorge and Koobi Fora in Africa, the oldest specimens being about 2.0 to 1.8 million years in age. On the other hand, there is a group of later specimens that show some features of *H. erectus* but are commonly regarded either as "archaic" representatives of *H. sapiens* or as belonging to *H. heidelbergensis*; these include specimens from Europe (Mauer, Arago, Bilzingsleben, and Petralona), northwestern Africa (Rabat and perhaps Salé and Sīdī 'Abd ar-Raḥmān), eastern and southern Africa (Kabwe, Elandsfontein, Ndutu, Omo, and Bodo), and Asia (the Ta-li find of 1978).

BODY STRUCTURE

Much of the fossil material discovered in Java and China consists of cranial bones, jawbones, and teeth. The few broken limb bones found at Chou-k'ou-tien have provided little information. It is possible that the complete femur excavated by Dubois at Trinil is more recent in age than the other fossils found there and not attributable to *H. erectus*. It comes as no surprise, therefore, that the greatest descriptive emphasis has been on the shape of the skull rather than other parts of the skeleton. The continuing discoveries in Africa (particularly at the Olduvai and Lake Turkana sites) have yielded a more complete picture of *H. erectus* anatomy.

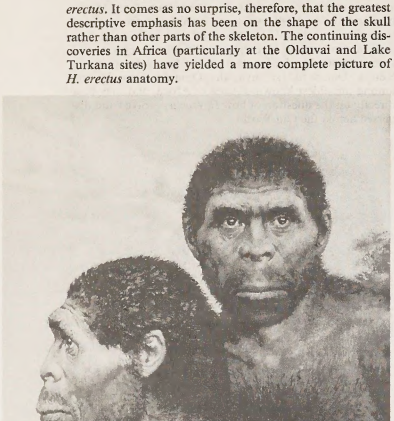

Figure 30: Artist's depiction of *Homo erectus*.
Painting by Zdenek Burian; reproduced with permission

The cranium of *H. erectus*, with its low profile and average endocranial (brain) capacity of less than 1,000 cubic centimetres, is distinctly different from that of other humans. The average endocranial capacity of modern *H. sapiens*, for example, is 1,350 cubic centimetres, although the range for recent humans is appreciable, perhaps 1,000 to 2,000 cubic centimetres. The upper part of the maximum estimated range for *H. erectus* endocranial capacity (1,200 cubic centimetres) thus overlaps with the lower values expected for *H. sapiens*.

Some difference in estimated brain size is apparent between the Javanese and the Chou-k'ou-tien populations of *H. erectus*. That is, the average capacity of the Chou-k'ou-tien fossils exceeds that of the Javanese by about 160 cubic centimetres. There is, however, an earlier, anomalous cranium from Kung-wang-ling, China, that is approximately contemporary with some Java fossils. It shares with the Javanese group a smaller cranial capacity (780 cubic centimetres). Theoretically, the difference in brain size between the two groups of Asian fossils may be the consequence of further evolution in later populations of *H. erectus*. Alternatively, it may simply be interpreted as representing the variation expected between sexes or between two separate populations or subspecies of *H. erectus*. Several African values are also available, and in the case of the Koobi Fora and Olduvai individuals these range from about 850 to 1,067 cubic centimetres.

While the cranial capacity of *H. erectus* falls short of that of *H. sapiens*, it far exceeds the capacities of the australopiths. The difference between *Australopithecus* and *H. erectus* is slightly greater than that between *H. erectus* and *H. sapiens*. Into the former gap fit the cranial capacities of *H. habilis* and *H. rudolfensis*. Clearly, the last word has not been written on their relationships.

The face of *Homo erectus*

Besides their brain capacity, the skulls of *H. erectus* show a number of other distinctive features. The face, which is preserved in only a few specimens, is massively constructed, and its lower parts project forward. The bone forming the wall of the nose is thinner and more everted than in earlier *Homo* or *Australopithecus*, and the nasal bridge is relatively high and prominent. This development suggests that *H. erectus* was well-equipped to conserve moisture that would otherwise be lost during exhalation. Such a physiological advantage would have allowed early African *H. erectus* to travel for longer periods in an arid environment. The braincase is low, with thick bones and sides that taper upward. Over the eye sockets is a strongly jutting browridge (supraorbital torus). There is a flattened forehead, and the part of the cranium immediately behind the browridge is appreciably constricted from side to side. A low ridge or crest of bone extends from the frontal bone along the midline of some skulls, and there tend to be strongly developed crests in the ear region. The broad-based skull has another ridge running across it. The area where the neck muscles attach is much larger than in *H. habilis* or *H. sapiens*. Other distinguishing features in *H. erectus* can be found on the underside of the skull, especially at the jaw joint. The lower jaw itself is deep and robust and lacks chin development. The teeth are on the whole larger than those of *H. sapiens*.

The femur is the most commonly recovered noncranial fossil. Apart from the puzzling Trinil specimen, a number of femurs have been found at Chou-k'ou-tien, and more have been recovered from sites in Africa. These bones resemble those of modern humans, and *H. erectus* must have walked upright efficiently. Its skeleton is robust, suggesting that the lifestyle of *H. erectus* was physically demanding. The limb bones also supply information about the size of *H. erectus*. Size influences behaviour and various aspects of anatomy, including bodily proportions. One measure of size is stature, or height. The femurs found at Chou-k'ou-tien and Koobi Fora are too broken to yield a good estimate of the height of these individuals, but accurate measurements of the boy's skeleton found at Nariokotome have been made. Although he was not fully grown, it is thought that the boy would have reached 180 centimetres (6 feet) in height.

Different interpretations of the fossils

The total pattern of the bodily structure of *H. erectus*, as preserved in the fossils, is different from that of *H. sapiens*, hence its classification as a separate species. Parts of its skeleton are more robust, but it is otherwise comparable to that of modern humans. The brain is relatively small, though not so small as that of *Australopithecus* and *H. habilis*. Unlike *H. sapiens* and *H. habilis*, later species of *Australopithecus* and *H. erectus* have thick skull bones and extraordinarily developed browridges. Some paleoanthropologists maintain that *H. erectus* has features not present

in its presumed ancestors or in *H. sapiens* and that Asian *H. erectus*, with a thick cranium and large adornments on the skull, could not have been on any direct evolutionary line to *H. sapiens*, noting that early *Australopithecus* and *H. habilis* are more ancient but had skulls more like ours, with thin bones and only modest enhancements on the cranium. These scientists point instead to early African *H. erectus*, sometimes referred to as a distinct species named *H. ergaster*, as the more probable ancestral form. This species is considered to have evolved, perhaps through an intermediate step (*H. heidelbergensis*), in the direction of modern humans.

Such a reading of the fossil record may be incorrect. In fact, there is very little evidence about the variability of features such as cranial thickness and external embellishments of the skull among even one population of *H. erectus*, let alone among different populations dispersed through two or three large continents. Practically nothing is known about the climatic or ecological conditions under which cranial thickening occurred. Also unknown is the relationship between skull growth and the brain enlargement that is such a striking feature of hominid evolution. These and many other questions must be answered before *H. erectus* can be either confirmed or written off as an ancestor of *H. sapiens*. In the meantime, all that can be said with any certainty is that *H. erectus*, in a broad geographic sense over the course of more than one million years, evolved from pre-*Homo erectus* (probably *H. habilis* or *H. rudolfensis*) to post-*Homo erectus*—that is, to *H. heidelbergensis* or perhaps directly to archaic *H. sapiens*.

BEHAVIORAL INFERENCES

Homo erectus's dwelling places

At Chou-k'ou-tien the remains of *H. erectus* were found in cave and fissure deposits. Although this does not prove that these hominids were habitual cave dwellers, the additional evidence of associated remains—such as stone, charred animal bones, collections of seeds, and what could be ancient hearths and charcoal—all points to *H. erectus* as having spent periods of time in the grottoes of Chou-k'ou-tien. On the other hand, the remains of Lan-t'ien, Trinil, Sangiran, and Modjokerto, as well as Ternifine, Olduvai, and Koobi Fora, were all found in open sites, sometimes in stream gravels and clays, sometimes in river sandstones, and sometimes in lake beds. These suggest that *H. erectus* also lived in open encampments along the banks of streams or on the shores of lakes and also that proximity to water was crucial to survival. These presumed campsites were revealed by excavation, and they contain abundant stone implements and stone chips that surely resulted from human manufacture. Fractured and partly burned bones of animals found at the sites indicate that *H. erectus* may have either hunted or scavenged meat.

There is little doubt that mastery of fire was an important factor in colonizing cooler regions. Indeed, this discovery may have sped the migrations of ancient humans into the chilly, often glaciated expanses of prehistoric Europe. Sooner or later humans started cooking their food, thus reducing the work demanded of their teeth. This in turn may have played an important part in minimizing the evolutionary advantage of big teeth, since cooked food needs far less cutting, tearing, and grinding than does raw food. This relaxation of the selective pressure favouring the survival of people with large, strong teeth may have led directly to a reduction in the size of the teeth—an important consideration given that this is one of the features distinguishing *H. sapiens* from *H. erectus*.

Chou-k'ou-tien has been cited as providing signs that humans had mastery of fire 400,000 years ago. Investigators reported ash and charcoal accumulations that resemble hearths, and it is possible that *H. erectus* used fire in the caves for warmth and for preparing food. However, more recent research shows that at least some of the "ash" is instead sediment probably deposited by water. Nevertheless, burned bones are present, and these relics may still speak to the ability of the Chou-k'ou-tien inhabitants to roast meat.

Other signs of the culture of *H. erectus* are implements found in the same deposits as their bones. Chopping tools and flakes made from split pebbles characterize both the Chou-k'ou-tien and Dmanisi deposits; both are members of a so-called Chopper chopping-tool family of industries.

Tools found in northwest Africa

At Tighenif in northwestern Africa, *H. erectus* was found in association with totally different kinds of stone implements; these comprise double-edged hand axes and scrapers that have been characterized as representing what archaeologists call an early Acheulean industry. This is part of the great Acheulean hand-ax industrial complex, remnants of which are found widely spread over large parts of Europe and Africa. An Acheulean industry is known also from Olduvai Gorge, as is a local, more ancient form of stone chopper manufacture known as the Oldowan industry, but the exact cultural associations of these stone tools with African *H. erectus* (as exemplified by OH 9) are uncertain.

Hence, *H. erectus* has been found associated in some parts of the world with a Chopper chopping-tool tradition and in other places with an Acheulean double-edged hand-ax industrial complex. Numerous animal bones occur also with the remains of *H. erectus*, and sometimes these bones seem to have been deliberately broken or charred. From this evidence it is sometimes inferred that *H. erectus* was a hunter. The brain, body size, and manufactured equipment of *H. erectus* were so superior to those of *Australopithecus* and *H. habilis* that it is highly probable that food-collecting techniques, including hunting, were also better. Many scientists hold that *Australopithecus* and *H. habilis* were more scavengers than hunters, perhaps at best opportunists who seized their chance when a weak, young, sick, or aged animal crossed their paths. Indeed, many of the animal bones found in australopith deposits are of juvenile and old individuals. Although larger animal bones have been recovered from *H. habilis* deposits, these have exhibited tooth marks of nonhuman predators as well as cut marks. *H. erectus*, on the other hand, seems to have been a confirmed hunter whose prey included animals of all age groups.

The diet of *Homo erectus*

It can credibly be supposed that, as with present-day hunters such as the African San (Bushmen) and the Australian Aboriginals, meat from the hunt formed only a part of the diet of *H. erectus*. Other juicy morsels may have been furnished by snakes, birds and their eggs, locusts, scorpions, centipedes, tortoises, mice and other rodents, hedgehogs, fish, and crustaceans. Even children could have caught many of these—as they still do in Africa's Kalahari Desert today, before being allowed to accompany the older men on the hunt. Vegetable food—such as fleshy leaves, fruits, nuts, roots, and tubers—also must have been important in the diet of *H. erectus*. Accumulations of hackberry seeds, for example, were found in the Chou-k'ou-tien cave deposits. There seems to be little doubt that *H. erectus* was omnivorous, for such a diet is the most opportunistic of all, and modern humans are the most opportunistic of all living primates. *H. erectus* was probably one of the earliest of the great opportunists, and it is likely that this attribute endowed the species with adaptability and evolutionary flexibility.

Another question that may be asked about *H. erectus* culture is whether there is any evidence of ritual. There is no sign that they buried their dead: no complete burials have been found, nor have graves, grave goods, or red ochre (a mineral used as a paint by later forms of hominids), either on or around any bones. Cannibalism was once inferred from the Ngandong (Solo) and Chou-k'ou-tien finds, but little credible evidence remains to support such a hypothesis.

RELATIONSHIP TO *HOMO SAPIENS*

The question of ancestry. A few researchers have generally opposed the view that *H. erectus* was the direct ancestor of later species, including *H. sapiens*. Louis Leakey argued energetically that *H. erectus* populations, particularly in Africa, overlap in time with more advanced *H. sapiens* and therefore cannot be ancestral to the latter. Some support for Leakey's point of view has come from analysis of anatomic characteristics exhibited by the fossils. By emphasizing a distinction between "primitive" and "derived" traits in the reconstruction of relationships between species, several paleontologists have attempted to show

that *H. erectus* does not make a suitable morphological ancestor for *H. sapiens*. Because the braincase is long, low, and thick-walled and presents a strong browridge, they claim that *H. erectus* shows derived (or specialized) characteristics not shared with more modern humans. At the same time, it is noted, *H. sapiens* does share some features, including a rounded, lightly built cranium, with earlier hominids such as *H. habilis*. For these reasons, some paleontologists (including Leakey) consider the more slender, or "gracile," *H. habilis* and *H. rudolfensis* to be more closely related to *H. sapiens* than is *H. erectus*. These findings are not widely accepted, however. Instead, studies of size in human evolution indicate that representatives of *Homo* can be grouped into a reasonable ancestor-to-descendant sequence showing increases in body size. Despite having a heavier, more flattened braincase, *H. erectus*, most particularly the African representatives of the species sometimes called *H. ergaster*, is not out of place in this sequence.

If this much is agreed, there is still uncertainty as to how and where *H. erectus* eventually gave rise to *H. sapiens*. This is a major question in the study of human evolution and one that resists resolution even when hominid fossils from throughout the Old World are surveyed in detail. Several general hypotheses have been advanced, but there is still no firm consensus regarding models of gradual change as opposed to scenarios of rapid evolution in which change in one region is followed by migration of the new populations into other areas.

The transition to *Homo sapiens*

Theories of gradual change. A traditional view held by some paleontologists is that a species may be transformed gradually into a succeeding species. Such successive species in the evolutionary sequence are called chronospecies. The boundaries between chronospecies are almost impossible to determine by means of any objective anatomic or functional criteria; thus, all that is left is the guesswork of drawing a boundary at a moment in time. Such a chronological boundary may have to be drawn arbitrarily between the last survivors of *H. erectus* and the earliest members of a succeeding species (*e.g.*, *H. sapiens*). The problem of defining the limits of chronospecies is not peculiar to *H. erectus*; it is one of the most vexing questions in paleontology.

Such gradual change with continuity between successive forms has been postulated particularly for North Africa, where *H. erectus* at Tighenif is seen as ancestral to later populations at Rabat, Temara, Jebel Irhoud, and elsewhere. Gradualism has also been postulated for Southeast Asia, where *H. erectus* at Sangiran may have progressed toward populations such as those at Ngandong (Solo) and at Kow Swamp in Australia. Some researchers have suggested that similar developments could have occurred in other parts of the world.

The supposed interrelation of cultural achievement and the shape and size of teeth, jaws, and brain is a theorized state of affairs with which some paleoanthropologists disagree. Throughout the human fossil record there are examples of dissociation between skull shape and size on the one hand and cultural achievement on the other. For example, a smaller-brained *H. erectus* may have been among the first humans to tame fire, but much bigger-brained people in other regions of the world living later in time have left no evidence that they knew how to handle it. Gradualism is at the core of the so-called "multiregional" hypothesis (see above *Evolution of the human family, Hominidae: The emergence of Homo sapiens*), in which it is theorized that *H. erectus* evolved into *H. sapiens* not once but several times as each subspecies of *H. erectus*, living in its own territory, passed some postulated critical threshold. This theory depends on accepting a supposed *erectus-sapiens* threshold as correct. It is opposed by supporters of the "out of Africa" hypothesis, who find the threshold concept at variance with the modern genetic theory of evolutionary change.

Theories of punctuated change. A gradual transition from *H. erectus* to *H. sapiens* is one interpretation of the fossil record, but the evidence also can be read differently. Many researchers have come to accept what can be termed a punctuated view of human evolution. This view suggests that species such as *H. erectus* may have exhibited little or no morphological change over long periods of time (evolutionary stasis) and that the transition from one species to a descendant form may have occurred relatively rapidly and in a restricted geographic area rather than on a worldwide basis. Whether any *Homo* species, including our own, evolved gradually or rapidly has not been settled.

The continuation of such arguments underlines the need for more fossils to establish the range of physical variation of *H. erectus* and also for more discoveries in good archaeological contexts to permit more precise dating. Additions to these two bodies of data may settle remaining questions and bring the problems surrounding the evolution of *H. erectus* nearer to resolution. (P.V.T./G.P.Ri.)

Neanderthals (Neandertals)

Now extinct, the most recent archaic humans, the Neanderthals, emerged between 200,000 and 100,000 years ago and were replaced by early modern humans between 35,000 and 28,000 years ago. Neanderthals inhabited Eurasia from the Atlantic regions of Europe eastward to Central Asia and from as far north as present-day Belgium southward to the Mediterranean and southwest Asia. Similar human populations lived at the same time in eastern Asia and Africa. Because Neanderthals lived in a land of abundant limestone caves, which preserve bones well and where there has been a long history of prehistoric research, they are better known than any other archaic human group. Consequently, they have become the archetypal "cavemen." The name Neanderthal (or Neandertal) derives from the Neander Valley near Düsseldorf, Germany, where quarrymen unearthed portions of a human skeleton from a cave in 1856.

FOSSIL EVIDENCE

The remains from the Neander Valley consist of 16 pieces, which were scientifically described shortly after their discovery. Immediately there was disagreement as to whether the bones represented an archaic and extinct human form or an abnormal modern human. The former view was shown to be correct in 1886, when two Neanderthal skeletons associated with Middle Paleolithic stone tools and bones of extinct animals were discovered in a cave at Spy, Belgium.

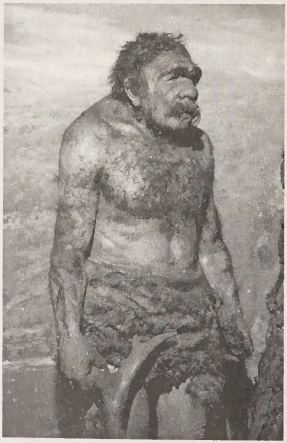

Figure 31: Reconstructed model of Neanderthal man (*Homo neanderthalensis*).
Tom McHugh—The Field Museum, Chicago/Photo Researchers



Figure 32: Neanderthal skull (replica), with *Homo sapiens* in background.
Frank Franklin II—AP/Wide World Photos

Early theories

From shortly after the Spy discovery to about 1910, a series of Neanderthal skeletons were discovered in western and central Europe. Using those skeletons as a basis, scholars reconstructed the Neanderthals as semihuman, lacking a full upright posture and being somewhat less intelligent than modern humans. According to that view, the Neanderthals were intermediate between modern humans and the apes, as no older human forms were then generally recognized. They were also considered to be too different from modern humans to be their ancestors. Only after World War II were the errors in this perception of Neanderthals recognized, and the Neanderthals have since come to be viewed as quite close evolutionarily to modern humans. This view has been reflected in the frequent inclusion of the Neanderthals within the species *H. sapiens*, usually as a distinct subspecies, *H. sapiens neanderthalensis*; more recently they have often been classified as a different but closely related species, *H. neanderthalensis*. Neanderthal skeletons have been found in caves and shelters across Europe, in southwest Asia, and eastward to Uzbekistan in Central Asia, providing abundant skeletal remains and associated archaeological material for understanding these prehistoric humans. The Neanderthals are now known from several hundred individuals, represented by remains varying from isolated teeth to virtually complete skeletons.

ORIGINS AND ANATOMY

The fossil evidence for the few hundred thousand years leading up to the time of the Neanderthals shows a gradual decrease in the size and frequency of anatomic characteristics of *H. erectus* and an increase in features more representative of Neanderthals. A gradual emergence of the Neanderthals from earlier regional populations of archaic humans can be inferred, probably across their entire geographic range. The changes between Neanderthal ancestors and the Neanderthals themselves highlight their characteristics. Brain size gradually increased to reach modern human volumes relative to body mass, although Neanderthal brains and braincases tended to be somewhat longer and lower than those of modern humans. Neanderthal faces remained large and especially long, similar to those of their ancestors, and they retained browridges and a projecting dentition and nose and had a receding chin. Their chewing teeth (premolars and molars) were small like those of early modern humans, and their chewing muscles and cheek regions had shrunk accordingly. Their incisor and canine teeth, however, remained large, like those of their ancestors, indicating their continued use as a vise or third hand.

Large-brained Neanderthals

The bodies of the Neanderthals changed little from those of their ancestors. They retained broad shoulders, extremely muscular upper limbs, large chests, strong and fatigue-resistant legs, and broad, strong feet. There is nothing in their limb anatomies to indicate less dexterity than modern humans or any inability to walk efficiently. The details of their hand bones, however, do suggest greater emphasis on power rather than precision grips. All of these features appear to have been maintained from their ancestors.

The Neanderthals differed in facial appearance from other archaic humans of East Asia and Africa, primarily in their retention of large incisors and canines, large noses, and long faces to support those teeth. In all archaic populations, facial massiveness and the size of premolars and molars were diminishing.

THE FATE OF THE NEANDERTHALS

The evolutionary fate of the Neanderthals is closely related to the origins of modern humans. Over the years, the Neanderthals have been portrayed as everything from an evolutionary dead end to the direct ancestors of modern European and western Asian populations. Fossil evidence indicates that modern humans first evolved in sub-Saharan Africa sometime prior to 100,000 years ago. Subsequently they spread northward after 40,000 years ago, displacing or absorbing local archaic human populations. As a result, the southwest Asian, Central Asian, and central European Neanderthals were absorbed to varying degrees into those spreading modern human populations and contributed genetically to the subsequent early modern human populations of those regions. Even in western Europe—a cul-de-sac where the transition to modern humans took place relatively late—there is fossil evidence for interbreeding between late Neanderthal and early modern humans.

Possible interbreeding

The anatomic changes between the Neanderthals and early modern humans involved largely a loss of the sturdiness characteristic of all archaic humans. Upper limbs became more gracile, although they were still very muscular

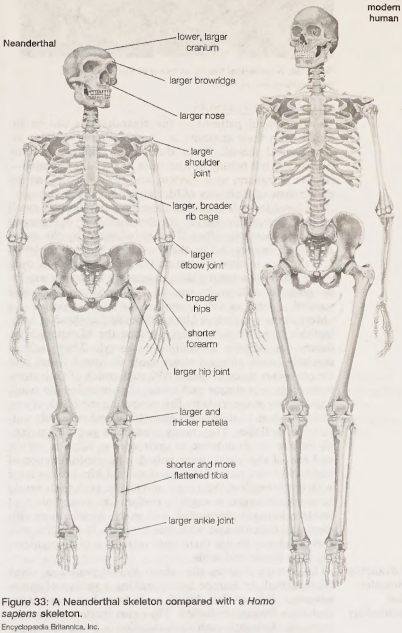

Figure 33: A Neanderthal skeleton compared with a *Homo sapiens* skeleton.
Encyclopædia Britannica, Inc.

by the standards of today's humans. The hand anatomy shifted to emphasize precision grips. Leg strength remained high, reflecting the mobility that characterized all Pleistocene hunting-and-gathering human populations. Front teeth became smaller and faces shortened, producing full chins and brows without ridges. Braincases became more elevated and rounded but not larger. Tool use and culture became more elaborate, but there are no anatomic features directly indicating that Neanderthals were smarter or less smart than other humans living at the time.



Figure 34: Neanderthal fossils as found at Kebara, Israel.
The Natural History Museum, London

BEHAVIORAL INFERENCES

The behavioral patterns of the Neanderthals can be inferred from their anatomy in combination with their archaeological record. From their fossil remains and the debris they left behind at hundreds of sites they created—in cave entrances, rock shelters, and the open air—an accurate view of their way of life can be put together.

The Neanderthals appear to have lived in relatively small groups, moving frequently on the landscape but reusing the same locations often. This is indicated by the small sizes of their sites and by the considerable depth of debris at a number of sites. The materials left behind show only minor variations among sites, suggesting that there was little planned differential use of the landscape—one site seemed to serve as well as another for most purposes.

Most of their early tool kits are described as those of a Paleolithic technological complex called the Mousterian industry (or Middle Paleolithic industry). They include carefully made chipped stone tools or broad flakes and simple spears made of wood. Although much of their stone technology was simple and crude, they occasionally made high-quality stone tools by first preparing the block of raw material so as to strike off symmetrical and relatively uniform stone flakes. They rarely used bone as a raw material, despite its abundance at their sites as kitchen debris, and few of their tools were hafted. The predominance of handheld thick stone flakes in their tool kits is associated with the strength of their arms and hands; such tools would have required great strength to perform the same tasks that modern humans accomplish with mechanically more-efficient implements and with less strength. It also fits with their tendency to use their front teeth as a vise, augmenting their hands and tools.

Advancing Neanderthal technology

This pattern changes after about 40,000 years ago, when Neanderthals in Europe began making a variety of more-advanced (Upper Paleolithic) tools from bone and stone that were frequently hafted. They also made personal ornaments. Although such sophistication is a late phenomenon for this group of archaic humans, it nonetheless shows clearly that they were fully capable of complex technological and social behaviours. This is all the more important as the earliest modern humans in southwest Asia left behind an archaeological record that is essentially indistinguishable from that of the Neanderthals.

Information about the Neanderthal diet consists mostly of the animal bones that they left behind, but there is rare evidence that they ate nuts, tubers, and other plant foods when available. The animal bones they abandoned indicate that they were able to hunt small and moderately large animals (goats, horses, and cattle) but were able to eat larger animals (*e.g.*, rhinoceroses and mammoths) only by scavenging from natural deaths. The bone chemistry of European Neanderthals indicates that they were highly carnivorous and therefore must have been reasonably effective hunters. The animals exploited for food closely reflect what was available in the surrounding countryside. Consumption of fish, birds, or shellfish appears to have been rare. There is simply no evidence for any systematic harvesting of wild plant or animal resources—a characteristic of modern hunter-gatherers in similar environments.

Neanderthals were the first human group to survive in northern latitudes during the cold (glacial) phases of the Pleistocene. They had domesticated fire, as evidenced by concentrations of charcoal and reddened earth found at their sites. Their hearths were simple and shallow, however, and must have cooled off quickly, providing little warmth through the night. Not surprisingly, Neanderthals exhibited anatomic adaptations to cold conditions, especially in Europe. Such features included large torsos and relatively short limbs, both of which maximized heat production and minimized heat loss.

The Neanderthals exhibited some uniquely modern features despite their archaic anatomy and their less-efficient foraging systems (as compared with those of modern human hunter-gatherers). They were the first humans to bury their dead intentionally, usually in simple graves. This indicates social systems sufficiently elaborate to make some kind of formal disposal of the dead desirable. They also occasionally created simple forms of personal decoration such as pierced pendants. Creation of artistic objects became well-developed among late Neanderthals associated with early Upper Paleolithic technologies.

The harsh life of Neanderthals

The difficult existence of the Neanderthals is reflected in their high frequency of traumatic injury. The remains of all older individuals show signs of serious wounds, sprains, or breaks. There are abundant signs of nutritional deprivation during growth, more than 75 percent of individuals showing evidence of growth defects in their teeth. Life expectancy was low; few Neanderthals lived past 40 years of age, and almost none lived past 50. Still, they were able to keep severely injured individuals alive, in some cases for decades. This again reflects a more advanced social organization.

The overall image of the Neanderthals, therefore, is one of archaic humans who shared a number of important characteristics with modern humans, including their large brains, manual dexterity and walking ability, and social sophistication. Like their archaic predecessors, however, their foraging systems were considerably less efficient than those of modern human hunter-gatherers, necessitating more-muscular limbs, greater endurance, and large front teeth. It was only with the emergence of modern humans that these archaic features disappeared, being superseded by more elaborate cultural behaviours and technologies.

(E.Tr.)

Homo sapiens

Latin for "wise man," *Homo sapiens* is the name of the species to which all modern human beings belong, and the only species of the genus *Homo* that is not extinct. The name *Homo sapiens* was applied in 1758 by the father of modern biological classification, Carolus Linnaeus. It had long been known that human beings physically resemble the primates more closely than any other known living organisms, but at the time it was a daring act to classify human beings within the same framework used for the rest

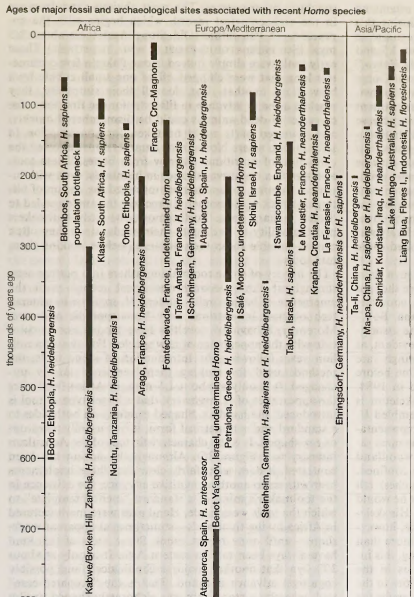

Figure 35: Chronological positions of *Homo* fossils.
Encyclopædia Britannica, Inc.

of nature. Linnaeus, concerned exclusively with similarities in bodily structure, faced only the problem of distinguishing *H. sapiens* from apes (gorillas, chimpanzees, orangutans, and gibbons), which differ from humans in numerous bodily as well as cognitive features. (Charles Darwin's treatise on evolution, *On the Origin of Species*, would come 101 years later.)

Since Linnaeus's time, a large fossil record has been discovered. This record contains numerous extinct species that are much more closely related to humans than to today's apes and that were presumably more similar to us behaviorally as well. Following our ancestors into the distant past raises the question of what is meant by the word "human." *H. sapiens* is human by definition, whereas apes are not. But what of the extinct members of the human family (Hominidae), who were clearly not us but were nonetheless very much like us? There is no definitive answer to this question. Although human evolution can be said to involve all those species more closely related to us than to the apes, the adjective *human* is usually applied only to ourselves and other members of our genus, *Homo* (*e.g.*, *H. erectus*, *H. habilis*). Behaviorally, only *H. sapiens* can be said to be "fully human," but even the definition of *H. sapiens* is a matter of active debate. Some paleoanthropologists extend the span of this species far back into time to include many anatomically distinctive fossils that others prefer to allocate to several different extinct species. In contrast, a majority of paleoanthropologists, wishing to bring the study of hominids into line with that of other mammals, prefer to assign to *H. sapiens* only those fossil forms that fall within the anatomic spectrum of the species as it exists today. In this sense, *H. sapiens* is very recent, probably originating less than 150,000 years ago (150 kya).

ORIGIN

The family Hominidae. Before about 1980 it was widely thought that distinctively hominid fossils could be identified from 14 to 12 mya. Since then genetic data and a steady trickle of new hominid fossil finds have pushed the earliest putative hominid ancestry back in time somewhat, to perhaps 8–7 mya.

The last remnants of a complex past

The pattern of human evolution, like that observed in most other evolutionarily successful groups, appears to have been a consistent process of trial and error. Historically, this process has been considered a more or less direct series of assumed improvements within a single lineage that eventually culminated in the burnished "perfection" of ourselves. As flattering to the ego as this picture may be, it is evidently quite wrong. Instead, human evolution has been throughout its long history a matter of experimentation, with new species being constantly spawned and thrown into the ecological arena to compete and, more often than not, become extinct. Viewed this way, we are simply the last surviving twig on a vast and intricately branching bush, rather than the sole occupant of a summit that has been laboriously climbed and, by extension, somehow earned. Fossils found since the early 1990s have begun to hint at just how complex the process has been in that four new genera of early hominids (*Sahelanthropus, Ardipithecus*, *Orrorin*, and *Kenyanthropus*) dating from 7 to 3 mya have been recovered from Kenya and Ethiopia.

The genus *Homo*. It is difficult to say how the wide variety of early hominids were interrelated. Moreover, although these ancient forms were clearly members of the same larger group, discerning exactly how any of them may have been connected to later species is problematic because of incomplete fossil evidence or different interpre-

tations of the same evidence. *Homo* may have originated as early as about 2.5 mya, though the record during this time is tantalizingly fragmentary. A variety of incomplete or broken fossils from the period between about 2.5 and 2.0 mya have been placed in the category of "early *Homo*," while slightly later fossils from Tanzania's Olduvai Gorge and elsewhere have been called *H. habilis*. Taken together, this hominid assemblage makes a rather odd assortment that is based more than anything else on a modest increase in the size of the brain compared with that of *Australopithecus* and its relatives (see Figure 12). Even more important in the assignment of these fossils to *Homo* may be the occurrence in the same geologic deposits of very primitive stone tools. The notion of "man the toolmaker" was very powerful in the early 1960s when *H. habilis* was named. Decades later, the species responsible for producing the first stone tools remains unknown, but it likely was relatively small-brained, with a body proportioned quite differently from our own.

Cranial remains dating to slightly less than 2 mya have been discovered at Koobi Fora, Kenya. These are thought to belong to the same species as the remarkably complete 1.6-million-year-old skeleton named "Turkana Boy," found at nearby Nariokotome. The nature of the association between the two finds is not yet completely evident, as even partial hominid skeletons are almost vanishingly rare as researchers delve deeper into the past to a time before the introduction of burial practices. Discovered in 1984, the slender-limbed, long-legged Nariokotome skeleton is the first solid evidence of an individual that resembled *H. sapiens* in overall bodily form. Here at last is a representative of a species that was definitely at home on the open savanna, emancipated from the forest and woodland environments to which its predecessors had been confined. Turkana Boy was 160 centimetres (5 feet 3 inches) tall when he died at age eight, and it is estimated that he would have topped 180 centimetres (6 feet) at maturity. His skeleton bears the basic hallmarks of our own; his face, however, was quite projecting, and his brain was little more than half the size of ours. Cranial traits notwithstanding, this individual clearly deserves to be classified with us in the genus *Homo*. He is now assigned by most authorities to the species *H. ergaster*, although some scientists still prefer the catchall species *H. erectus*, which was originally based on specimens from Java discovered in the 1890s; others include him in an extended interpretation of *H. sapiens*.

Emergence of the human body form

Once modern human body proportions had been achieved, such species could indulge their newfound wanderlust. By about 1.8 mya hominids, previously confined to Africa, had roamed as far afield as China and Indonesia. In their new territories they diversified, as might be expected, with new species emerging in different regions. *Homo erectus* appeared in eastern Asia early on; the earliest European hominid, *H. antecessor*, is known only from considerably later, about 800 kya. Africa appears to have been the source of not just one but successive waves of hominid emigrants, including *H. heidelbergensis*, which had originated by 600 kya and found its way to Europe by 500 kya. In Europe an early representative of *H. heidelbergensis* may have given rise to the groups that included the Neanderthals (*H. neanderthalensis*), who populated Europe and western Asia from about 200 to 30 kya. Africa, however, apparently continued to produce species that figure more directly in the ancestry of today's *H. sapiens*.

Throughout there was a tendency for new hominid species to acquire ever-larger brains. *Homo heidelbergensis*, for example, had a brain smaller than ours, while those of the Neanderthals were on average larger than the *H. sapiens* average. This increase must have come at a cost, because brain tissue expends significant amounts of energy. There must have been benefits of a larger brain, but what those benefits were can only be guessed—quantifying human intelligence is problematic even among living humans, let alone extinct ones.

BEHAVIORAL INFERENCES

Tools and shelters. The story of hominid evolution is one of increasing behavioral complexity, but, because behaviour does not leave direct fossil evidence, clues must be sought in other sources. The most obvious candidates are in the archaeological record, which begins with the appearance of Paleolithic (Old Stone Age) tools about 2.5 mya. (See PREHISTORIC PEOPLES AND CULTURES.) These early tools were simple indeed: stone flakes a few centimetres long that were chipped off of one small cobble by a blow from another. But, for all their simplicity, they marked a major advance in lifestyle: for the first time, the carcasses of dead animals could be dismembered quickly, and favoured parts could be taken for consumption to safer places, where blows from hammerstones allowed the extraction of nutritious marrow from bones. These tools also signify a cognitive advance in hominids; even with intensive training, no ape has yet mastered the notion of hitting one rock with another at precisely the angle needed to detach a sharp flake. Furthermore, the early toolmakers had the ability to anticipate their needs, since they often carried suitable rocks long distances before making them into tools.

The history of stone toolmaking ushers in a pattern seen throughout the paleoanthropological record until the emergence of behaviorally modern *H. sapiens*: in general, technological innovations have been sporadic and rare. Moreover, behavioral novelties have tended not to coincide with the appearance of new species. For almost a million years following the introduction of stone tools, the methods used for making them remained largely unchanged. It is only at about 1.6 mya, in Africa (well after the appearance of *H. ergaster*), that a larger type of tool is introduced: the hand ax. Shaped carefully on both sides to a standard and symmetrical form, it was usually teardrop- or egg-shaped. It is the characteristic tool of the Acheulean industry (see Figure 36). Although the notion has been contested, it does seem fairly clear that these implements bear witness to another cognitive advance: the existence in the toolmaker's mind of a standard "mental template" to which the tools were made. Hand axes were manufactured in Africa by the thousands—sometimes at apparent workshops—until quite recent times. Stone tools of this kind have always been rare in eastern Asia. It is only at about 300 kya that another major technological (and possibly cognitive) advance is found. This is the "prepared-core" tool, whereby a stone core was elaborately shaped until a single blow, perhaps with a hammer made of a "soft" material such as bone, would detach a virtually finished tool with a continuous cutting surface around its periphery. The great masters of this technique were the Neanderthals, whose possession of language has long been debated. Regardless, it has been demonstrated (in studies with people) that language is not required for the transmission of the skills needed to make tools of this kind.

Hand-ax workshops

The stone tool record is well-preserved, but it is only an indirect reflection of overall lifestyle and cognitive capacities. It is still unknown, for example, whether the earliest tool users hunted extensively or merely scavenged animal remains. It is likely that, if they hunted, it was for small prey. Nonetheless, metabolic studies of bone suggest that

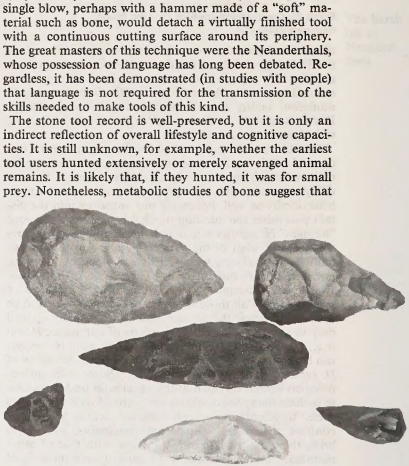

Figure 36: Tools of the Acheulean and Mousterian industries (replicas).
Skulls Unlimited International, Inc.

some *Australopithecus* may have eaten substantially more meat than chimpanzees do today.

Most authorities had guessed that efficient ambush-hunting was an invention of *H. sapiens*, but 400,000-year-old wooden throwing spears found in 1995 at Schöningen, Germany, may suggest otherwise. Unlike thrusting spears, which must be used at close range and with considerable risk, these 2-metre (6.6-foot) javelin-like weapons have their weight concentrated at the front and therefore could have been hurled from a safe distance. The age of the location at which these spears were found puts them within the period of *H. heidelbergensis*.

Homes and hearths

Also at 400 kya there is the first convincing evidence of two other innovations: the domestication of fire in hearths and the construction of artificial shelters. At Terra Amata in southern France, traces of large huts have been found. The huts were formed by embedding saplings into the ground in an oval and then bringing their tops together at the centre. Stones placed in a ring around the hut braced the saplings. Some of these huts were found to contain hearths scooped in the ground and lined with burned stones and blackened bones. These sites represent some of the earliest definitive proof of fires deliberately maintained and used for cooking, although 700,000-year-old hearths are reported from a site in Israel. (Reports of most earlier fire domestication have been contested on various grounds.)

Prior to the advent of *H. sapiens*, archaeological sites are generally random scatterings of detritus of various types—mostly butchery sites and sites where groups lived at later times. In the dwelling places of behaviorally modern early *H. sapiens*, on the other hand, there is a definite pattern in the use of space: toolmaking was done in one place, cooking in another, sleeping elsewhere. The earliest intimations of such partitioning are found at the South African site of Klasies River Mouth, perhaps dating to more than 100 kya (see Figure 35). This pattern is also typical of sites left behind by the earliest European *H. sapiens*, who colonized that continent many tens of thousands of years later. Also found at African sites are the first suggestions of symbolism and the complex behaviours that characterize *H. sapiens* worldwide today—behaviours that were effectively absent from the repertoires of their predecessors. At Blombos Cave, near Africa's southern tip, was found an ochre plaque more than 70,000 years old that is engraved with an unmistakably geometric motif. This and other early African sites have produced engraved ostrich eggshells and snail shells pierced for stringing and bodily adornment; these date from 70 to 50 kya. It is also in Africa that the earliest evidence appears for such modern behaviours as long-distance trade and the mining of flint for artifact production.

The Cro-Magnons and the Neanderthals. The most striking evidence for a distinct cognitive contrast between modern humans and all their predecessors, however, comes from Europe. *H. sapiens* came late to this continent, entering about 40 kya, and brought a new kind of stone tool based on striking long, thin "blades" from a carefully prepared long core. These Aurignacian tools were accompanied by a kit of implements that for the first time were made out of materials such as bone and antler and that were treated with exquisite sensitivity to their particular properties. In short order these Europeans, the so-called Cro-Magnons, left a dazzling variety of symbolic works of prehistoric art. The earliest known sculptures—delicate small carvings in ivory and bone—are about 34,000 years old. From about the same time come the earliest musical instruments, bone flutes with complex sound capabilities. Also from this time come the first known notations. These markings were made on bone plaques, one of which has been interpreted as a lunar calendar. By 30 kya the Cro-Magnons were already creating spectacular animal paintings deep in caves, most of which are accompanied by numerous geometric symbols.

Cro-Magnons as the first artists

Domestic items were regularly decorated and engraved by the Cro-Magnons. Burials, already practiced by the Neanderthals in a simple form, became complex, and graves were often crammed with goods that were likely thought to be useful to the deceased in an afterlife. Clay figurines were soon baked in primitive but remarkably effective kilns, and by about 27 kya delicate eyed needles made of bone heralded the advent of couture. It is hard to ask for better proof that the Cro-Magnons were modern *H. sapiens* cognitively equipped with all the intellectual faculties of today's people. Nobody would dispute, for example, that the Cro-Magnons had language; such a claim is highly arguable in earlier Stone Age *H. sapiens* and Neanderthals.

The Cro-Magnons contrasted strikingly with the Neanderthals, the hominids they had found already living in Europe upon their arrival and whom they replaced entirely over the next 10,000 to 12,000 years. While symbolic behaviours are typical of all groups of living humans, not all such groups have left behind symbolic records as dramatic as those of the Cro-Magnons. Nonetheless, there is no doubt that the Cro-Magnons and the Neanderthals perceived and interacted with the world in entirely different ways. The Cro-Magnons were people with whom we could relate on our own terms; as such, *H. sapiens* is not simply an incremental improvement on previous hominids. As the archaeological record eloquently indicates, our species is an entirely unprecedented phenomenon.

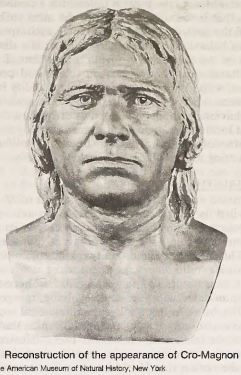

Figure 37: Reconstruction of the appearance of Cro-Magnon man.
Courtesy of the American Museum of Natural History, New York

Exactly when and where this new phenomenon initially occurred is problematic, but again the earliest evidence for the new behavioral pattern comes from Africa, and, as is discussed in the section below, the earliest anatomic intimations for the origin of *H. sapiens* also come from that continent. However, anatomic and cognitive "modernities" do not seem to have developed hand in hand; evidently there was a time lag between the establishment of modern anatomy (which appears to have come first) and modern behavioral patterns. While perhaps counterintuitive, this observation actually makes sense. Any innovation must take place within a species, since there is no place else it can do so. Natural selection is, moreover, not a creative force. It merely works on variations that come into existence spontaneously—it cannot call innovations into existence just because they might be advantageous. Any new structure or aptitude has to be in place before it can be exploited by its possessors, and it may take some time for those possessors to discover all the uses of such novelties. Such seems to have been the case for *H. sapiens* in that the earliest well-documented members of our species appear to have behaved in broadly the same manner as Neanderthals for many tens of thousands of years. It is highly unlikely that another species anatomically indistinguishable from *H. sapiens* but behaviorally similar to Neanderthals was supplanted worldwide in an extremely short span of time. Therefore, it seems appropriate to conclude that a latent capacity for symbolic reasoning was present when anatomically modern *H. sapiens* emerged and that our forebears discovered their radically new behavioral abilities somewhat later in time.

Evolution is not predetermined

Language. A cultural "release mechanism" of some sort was necessarily involved in this discovery, and the favoured candidate for this role is language, the existence of which cannot be inferred with any degree of confidence from the records left behind by any other species but our own. Language is the ultimate symbolic activity, involving the creation and manipulation of mental symbols and permitting the posing of questions such as "What if?" Not all components of human thought are symbolic (the human brain has a very long accretionary, evolutionary history that still governs the way thoughts and feelings are processed), but it is certainly the addition of symbolic manipulations to intuitive processes that makes possible what is recognized as the human mind.

The origins of this mind are obscure indeed, especially as scientists are still ignorant of how a mass of electrochemical signals in the brain gives rise to what we experience as consciousness. But the invention of language would plausibly have released the earliest of the cultural and technological innovations that symbolic thought makes possible—in the process unleashing a cascade of discoveries that is still ongoing. One of the most striking features of the archaeological record that accompanies the arrival of behaviorally modern *H. sapiens* is a distinct alteration in the tempo of innovation and change. Significant cultural and technological novelties had previously been rare, with long periods of apparent stability intervening between relatively sudden episodes of innovation. But once behaviorally modern *H. sapiens* arrived on the scene, different local technological traditions—and, by extension, other forms of cultural diversity—began to proliferate regularly, setting a pace that is still gathering today.

BODY STRUCTURE

Accounting for anatomic variations

As intimated above, the physical definition of *H. sapiens* is bedeviled by a basic divergence of views among paleoanthropologists. One school of thought derives its philosophy from the "single-species hypothesis" popular in the 1960s. This hypothesis held that two kinds of culture-bearing hominids could not, on principle, exist at any one time and that, as a result, all hominid fossils had necessarily to be accommodated within a single evolving lineage. By the mid-1970s, however, a rapidly expanding fossil record had begun to reveal a variety of extinct hominids that simply could not be contained within this linear construct. The proponents of the single-species hypothesis thus began to shift to the notion that *H. sapiens* is in fact an enormously variable species with roots extending far back in time to the era of *H. habilis*, some 2 mya. All subsequent hominids (including *H. erectus*, *H. neanderthalensis*, etc.) are in this view classifiable within *H. sapiens*. The tremendous anatomic variety among the populations that would compose this single species are then credited to separate evolutionary and adaptive histories in different parts of the Old World. Meanwhile, the reproductive integrity of this huge and diversifying species would have been maintained over time by interbreeding between local populations in the peripheral areas where they would have come into contact. According to those who support such regional continuity, modern variants of humankind would have resulted from long quasi-separate evolutionary histories. In this so-called "multiregional" scenario, Australian Aboriginals are derived from Java man (*i.e.*, Javanese *H. erectus*), modern Chinese from Peking man (Chinese *H. erectus*), today's Europeans from the Neanderthals (*H. neanderthalensis*) with some admixture from Cro-Magnons, and so on.

This formulation, which places the roots of today's geographically distinctive groups of *H. sapiens* extremely deep in time, does not accord well with how the evolutionary process is known to work. Anatomic innovations can become fixed only within small, effectively isolated populations; large populations simply have too much genetic inertia for changes to occur throughout the species. This multiregional notion, moreover, implies an evolutionary pattern that is at variance with that of all other successful mammalian groups, not to mention the diversity that is already recognized among the very early hominids. Taxonomically, it also stretches the morphological notion of species beyond its limits.

The alternative model, called the "out of Africa"—or, more cautiously, the "single-origin"—theory of human emergence, sees the anatomic diversity of the hominid fossil record as representing a substantial diversity of species. In its bony structure, *H. sapiens* is quite distinctive, boasting a relatively lightly built skeleton distinguished in many anatomic details from its closest relatives. In the cranium a high, rounded, and quite thin-boned braincase overhangs a greatly reduced face that is not expanded by large air sinuses. This face is topped by small or only modestly pronounced browridges that are uniquely divided into distinct central and lateral halves. In the lower jaw, the chin is not simply a swelling in the midline of the mandible (as can be found in certain other hominids) but a complex and distinctive structure that does not exist in other members of the human family. This list could continue with many other features.

If we define ourselves in terms of a suite of anatomic characteristics, few representatives of *H. sapiens* appear in the fossil record until comparatively recent times. Indeed, the first intimations of our distinctively modern anatomy come from southern and eastern Africa only in the period between about 160 and 100 kya. Unfortunately, most of the fossils concerned (from such sites as Klasies River Mouth, Border Cave, and Omo) are fragmentary, or their dates are questionable. Still, the unmistakable signal they send is that *H. sapiens*, in the sense of a creature that looked just like us in its essential bony attributes, did not exist in Africa before about 160 kya.

Defining *Homo sapiens* with DNA

This conclusion of the single-origin hypothesis matches the one reached by molecular geneticists who analyze the distributions of different types of mitochondrial DNA (mtDNA) in the cells of living human populations. This form of DNA consists of a tiny ring of hereditary material that actually lies outside the nucleus of the cell and is passed solely through the maternal line. It is not recombined between generations, as is nuclear DNA, and it seems to accumulate changes quite rapidly, which makes it ideal for analysis of recent evolutionary events. Comparisons of mtDNA samples derived from people all over the world point to the common descent of all modern humans from a small population that existed about 150 kya. In addition, the African samples show more variability in their mtDNA than do those of other continents, suggesting that African populations have been diversifying longer. Finally, the mtDNA types of native Asians and Europeans are subsets of the African mtDNA types, again suggesting that other populations of modern humans ultimately derived from an African one. For all these reasons, it appears that we originated as an anatomically distinctive species quite recently and probably somewhere in the continent of Africa.

The distinctiveness of *H. sapiens* has also been emphasized by a remarkable technological achievement in molecular genetics: the extraction of small stretches of undegraded mtDNA from Neanderthal samples. The few Neanderthal mtDNA sequences obtained so far lie entirely outside the envelope of variation offered by modern human samples from all over the world. Indeed, they are different enough to suggest that the lineages leading to *H. neanderthalensis* on the one hand and to *H. sapiens* on the other split approximately 500 kya. This observation supports a scenario whereby a European diversification of hominids culminating in the Neanderthals was descended from a population of *H. heidelbergensis* that had exited Africa. Similarly, East Asian hominids such as *H. erectus* were descended from an earlier wave of African émigrés (perhaps *H. ergaster* or a related species) that had spilled forth more than a million years earlier. Later, between about 100 and 50 kya, a final exodus of *H. sapiens* (or successive waves of such emigrations) ultimately led to the replacement of those indigenous (albeit ultimately African-derived) Asians and Europeans. There is ample evidence from Europe that the previously successful Neanderthals succumbed quite rapidly to the arrival of the Cro-Magnons, and new dates of about 40 kya for late-surviving *H. erectus* in Java suggest that invading *H. sapiens* may have accomplished a similar feat of replacement in Indonesia about the same time.

One of the best-preserved early fossils that bears all the anatomic hallmarks of *H. sapiens* is a skull dated to about 92 kya from the Israeli site of Jebel Qafzeh. This part of the Middle East, called the Levant, is often regarded as a biogeographic extension of Africa, so perhaps the discovery of this fossil in this particular location is not surprising. The specimen is a fractured but quite complete example of an individual whose skeleton is typically *H. sapiens* but whose cultural context is Mousterian—the name also given to the stone tool industry of the Neanderthals (see Figure 36). Indeed, all hominid fossils known from the Levant in the period between about 100 kya and 50 to 40 kya are associated with Mousterian tool kits, whether they belonged to *H. neanderthalensis* or *H. sapiens*. Apparently, these two physically distinctive hominid species managed to conduct a long coexistence in the limited confines of the Levant for upward of 50 millennia—about five times as long as it took the Cro-Magnons to eliminate the Neanderthals from the vast area of Europe. Exactly how the two forms managed this is unknown, but one suggestion involves a kind of time-sharing, for the sparse record contains no definite evidence of temporal coexistence. If the Neanderthals evolved in comparatively frigid Europe, it is possible that they were "cold-adapted," as their rather stocky frames might suggest. Perhaps early *H. sapiens*, having originated in Africa, was "heat-adapted." It is thus possible that the Neanderthals withdrew from the Levant in warmer times while the *H. sapiens* population advanced northward. In colder times, on the other hand, the reverse might have occurred. Whatever the case, what seems most significant is that once blade-based tools, similar though not identical to those later used by the Cro-Magnons, were introduced in the Levant around 45 kya, the Neanderthals rapidly disappeared. This is not absolutely conclusive evidence, but it does appear that when the Levantine *H. sapiens* had devised a technology that in at least one way is associated with modern humans, there is no longer evidence of coexistence.

Recent coexistence of human species

The fact that modern anatomy and modern behaviour were not established at the same time is not entirely surprising, but it does complicate attempts to define *H. sapiens*. We tend to pride ourselves on our unique cognitive qualities rather than anatomic minutiae. Yet, biologically speaking, we are most sensibly defined by physical appearance. This is especially true if our cognitive potential was born with the genetic changes that determined our distinctive modern anatomy rather than later, when our unusual cognitive capacity finally began to be expressed. Our earliest anatomically modern ancestors may have behaved in their day very much like Neanderthals, but would one of them, transplanted as a child to a modern society, develop cognitively into a recognizably modern adult—as almost certainly no Neanderthal would have been able to do? Probably so, but the answer to this question can never be known with certainty.

MODERN POPULATIONS

Homo sapiens is now crammed into virtually every habitable region of Earth, yet our species still bears the hallmarks of its origin as a tiny population inhabiting one small corner of the world. The variation in DNA among all the widespread human populations of today is less than what is found in any population of living apes. This is very surprising, given that there are so few apes in such small geographic areas—conditions that one might expect to produce a more homogeneous gene pool. The inevitable conclusion is that ancestral *H. sapiens* quite recently passed through a "bottleneck" in which the entire human population was reduced to a few hundred or perhaps a couple of thousand individuals, perhaps approximately 150 kya. Such a population size would be sufficiently small for a set of unique traits to become established, making it plausible that one small group would be the population from which *H. sapiens* emerged as a new, isolated reproductive entity.

The past few hundred thousand years have been a period during which climates have oscillated constantly between warmer and colder and also between wetter and drier. During these times, sea levels have repeatedly risen and fallen, creating islands and expanding landmasses. From a tiny population that most likely lived in Africa, our species spread, directed in its wanderings by the vagaries of climate, environment, and competition with species both human and nonhuman. This population spread first out of Africa, then throughout the Eurasian landmass and into Australasia, and finally into the New World and the Pacific Islands. The initial expansion was almost certainly the result of population increase as opposed to nomadic travels. This spread was assuredly not uniform but episodic and opportunistic, with frequent false starts, mini-isolations, and recoalescences. The physical variety of humankind today, while striking, is actually superficial, and it reflects this checkered history.

During the history of *H. sapiens*, local populations have developed various physical as well as cultural and linguistic differences. Some of these physical variations must have been controlled by the environment, others by purely random factors. It is clear, for example, that variations in skin colour are responses to variations in the intensity of sunlight in different climates. The dark pigment melanin protects against the highly damaging effects of the sun's ultraviolet (UV) radiation, and the darkest skins occur in the tropics, where such radiation is most intense (see Figure 38). In contrast, skins at higher latitudes tend to be pale, which allows the less-intense UV radiation there to penetrate the skin and promote the synthesis of essential factors such as vitamin D. Similarly, populations living in hot, dry areas tend to be taller and more slender than those living in very cold climates, because they need to lose heat rather than retain it as a rounder body does. On the other hand, nobody knows why some populations have thinner lips than others. This and other variations are inconsequential to fitness and are likely to be the mere results of random chance.

Current variations in *Homo sapiens*

Scientists have always had difficulty classifying people into groups on the basis of variation, and the reason is simple. Genetically, only two processes can take place within a species. One of these processes is the diversification of local populations—a routine and unremarkable event that requires some degree of isolation of local groups. The other is the reintegration of populations and the consequent blending of characteristics via interbreeding when contact is reestablished. Human populations show the results of both processes as driven by the climatic shifts of ice ages. Today, although it is generally possible to tell an Asian from a European from an African, many individuals defy such categorization, and boundaries are impossible to draw. This is why, from a biologist's point of view, trying to define "races" is impossible if not pointless. Race is instead a social construct addressed by cultural anthropology.

Still, tracing the history of our species' spread and diversification is undeniably fascinating, and several genetic approaches have been used to try to unravel it. In addition to mtDNA and its male counterpart, the Y chromosome, DNA from the Human Genome Project will also help clarify our relatively short but astonishingly complex history. The interpretation of mtDNA divergence shows the *H. sapiens* branch of the family tree to be rooted in Africa some 150 kya. It identifies four descendant mtDNA lineages (A, B, C, and D) among Native Americans. These four lineages are also present in continental Asians, as are lineages designated E, F, G, and M. Europeans show a different set of lineages, called H, I, J, and K as well as T through X. Africans present one principal lineage called L, with three major variants. One of these, L3, seems to have been the founder of both the Asian and the European groupings. Using the differences (genetic substitutions) observed among the lineages, the L3 emigrants are calculated to have reached Europe between about 51 and 39 kya, a date that is in good agreement with the archaeological record. But there are some apparent anomalies in these data. For example, the rare European X lineage has been identified in some northern Native Americans. This cannot be explained by recent intermarriage, since this lineage appears to have originated in America in pre-Columbian times. As the genes of more populations are studied, a more detailed picture of past human population movements and integrations around the world will emerge. (I.Ta.)

RACE

The many meanings of race

The modern meaning of the term *race* with reference to humans began to emerge in the 17th century. Since then it has had a variety of meanings in the languages of the Western world. What most definitions have in common is an attempt to categorize peoples primarily by their physical differences. In the United States, for example, the term *race* generally refers to a group of people who have in common some visible physical traits, such as skin colour, hair texture, facial features, and eye formation. Such distinctive features are associated with large, geographically separated populations, and these continental aggregates are also designated as races, as the "African race," the "European race," and the "Asian race." (Some experts suggest there are five or more geographic races.) Many people think of race as reflective of any visible physical (phenotypic) variations among human groups, regardless of the cultural context and even in the absence of fixed racial categories.

The term *race* has also been applied to linguistic groups (the "Arab race" or the "Latin race"), to religious groups (the "Jewish race"), and even to ethnic groups having few or no physical traits that distinguish them from their neighbours (the "Irish race," the "Slavic race," the "Chinese race"). Even political entities or nationalities are sometimes designated as races (the "French race," the "Spanish race," "the Polish race," etc.).

Most scholarship in the 20th century reflected the popularly held view that races and race differences are based on biophysical characteristics. For much of the 20th century, scientists attempted to identify, describe, and classify human races and to document their differences and the relationships among them. Some scientists used the term *race* for subspecies, subdivisions of the human species which were presumed sufficiently different biologically that they might later evolve into separate species.

At no point, from the first rudimentary attempts at classifying human populations in the 17th and 18th centuries to the present day, have scientists agreed on the number of races of humankind, the features to be used in the identification of races, or the meaning of *race* itself. Experts have suggested a range of different races varying from three to more than 60, based on what they have considered distinctive differences in physical characteristics alone (these include hair type, head shape, skin colour, height, and so on). The lack of concurrence on the meaning and identification of races continued into the 21st century, and contemporary scientists are no closer to agreement than their forebears. Thus, *race* has never had a precise meaning.

Twentieth-century research

Although most people continue to think of races as physically distinct populations, scientific advances in the 20th century have shown that human physical variations do not fit a "racial" model. There are no genes that can identify distinct groups that accord with the conventional race categories. DNA analyses have proved that all humans have much more in common, genetically, than they have differences. Geographically widely separated populations vary from one another in only about 6 to 8 percent of their genes. Because of the overlapping of traits that bear no relationship to one another (such as skin colour and hair texture) and the inability of scientists to cluster peoples into discrete racial packages, modern researchers argue that the concept of race has no biological validity.

Many scholars in other disciplines now accept this relatively new scientific understanding of biological diversity in the human species. Moreover, they have long understood that the concept of race as relating solely to phenotypic traits encompasses neither the social reality of race nor the phenomenon of "racism." Prompted by advances in other fields, particularly anthropology and history, scholars began to examine race as a social and cultural, rather than biological, phenomenon and have determined that race is a social invention of relatively recent origin. It derives its most salient characteristics from the social consequences of its classificatory use. The idea of "race" began to evolve in the late 17th century, after the beginning of European exploration and colonization. As many scholars saw it at the turn of the 21st century, race was a folk ideology about human differences associated with the different populations—Europeans, Amerindians, and Africans—that came together in the New World. In the 19th century, after the abolishment of slavery, the ideology fully emerged as a new mechanism of social division and stratification.

"Race" as a mechanism of social division

NORTH AMERICA

Racial classifications appeared in North America, and in many other parts of the world, as a form of social division predicated on what were thought to be natural differences among human groups. Analysis of the folk beliefs, social policies, and practices of North Americans about race from the 18th to the 20th century reveals a fundamental ideology about human differences that may be termed a "racial worldview," a systematic, institutionalized set of beliefs and attitudes that include the following components:

1. All the world's peoples can be divided into biologically separate, discrete, and exclusive populations called races. A person can belong to only one race.
2. Phenotypic features, or visible physical differences, are markers or symbols of race identity and status. Because an individual may belong to a racial category and not have all or any of the associated physical features, racial scientists early in the 20th century invented an invisible internal element, "racial essence," to explain such anomalies.
3. Each race has distinct qualities of temperament, morality, disposition, and intellectual ability. Consequently, races have different behaviours that are linked to their physical differences; *i.e.,* each race has distinct behavioral traits.
4. Races are unequal. They can, and should, be ranked on a gradient of inferiority and superiority. As the 19th-century biologist Louis Agassiz observed, since races exist, we must "settle the relative rank among [them]."
5. The behavioral and physical attributes of each race are inherited and innate, therefore fixed, permanent, and unalterable.
6. Distinct races should be segregated and allowed to develop their own institutions, communities, and lifestyles, separate from those of other races.

Racial ideology institutionalized

These are the beliefs that wax and wane but never entirely disappear from the core of the American version of race differences. From its inception, racial ideology accorded inferior social status to people of African or Native American ancestry. This ideology was institutionalized in law and social practice, and social mechanisms were developed for enforcing the status differences.

SOUTH AFRICA

Although race categories and racial ideology are both arbitrary and subjective, race was a convenient way to organize people within structures of presumed permanent inequality. South Africa's policy of apartheid exhibited the same basic racial ideology as the North American system but differed in two respects: the systematic state classification of races and the creation of an intermediate "racial" category; the Coloured category, for historical reasons, was made distinct and defined as those who were neither blacks (called Bantus or natives), most of whom retained their own traditional cultures, nor whites (Europeans), who brought different cultural forms to South Africa. The relative exclusiveness of South Africa's race categories was compromised by an institutionalized mechanism for changing one's race, the Race Classification Board established by the Population Registration Act of 1950. This body, unique to South Africa, adjudicated questionable classifications and reassigned races.

LATIN AMERICA

In the Latin American territories, a biologically mixed population emerged shortly after the arrival of the Spanish and Portuguese conquistadors and their African servants and slaves (primarily men). The resulting genetic mix of European and African peoples with indigenous people made it difficult to structure society on the basis of phenotype alone. Latin American colonists recognized the biologically mixed peoples and attempted to devise descriptive categories that reflected the mixtures of Europeans and Indians, Europeans and Africans, Indians and Africans, etc. These descriptive categories were not "races" but subjective observations about individuals. Each colonial area differed in the terms used. In Mexico (New Spain), for example, there were *mestizos* (offspring of a Spanish man and an Indian woman), *castizos* (offspring of a *mestizo* man and a Spanish woman), *mulattos* (offspring of a Spanish woman and an African man), *moriscos* (offspring of a Spanish man and a mulatto woman), and seven more categories. These differences continued in the modern nation-states.

None of the Latin areas was able to develop an ideology of exclusiveness because of the pervasive mixtures of peoples. "Whiteness," nonetheless, was interpreted as the superior social category, and it incorporated many people of mixed background. The class stratification systems of all the Latin colonies were not based solely on ancestry but on factors such as education, income, occupation, and lifestyles. In the 19th and 20th centuries large numbers of Europeans immigrated to South America, and their racial beliefs strengthened the notion that "whiteness" (having more European characteristics) was superior to "blackness" (having more African characteristics).

The difference between racism and ethnocentrism

Although they are easily and often confused, race and racism must be distinguished from ethnicity and ethnocentrism. While extreme ethnocentrism may take the same offensive form and may have the same dire consequences as extreme racism, there are significant differences between the two concepts. Ethnicity, which relates to culturally contingent features, characterizes all human groups. It refers to a sense of identity and membership in a group that shares common language, cultural traits (values, beliefs, religion, customs, etc.), and a sense of a common history. All humans are members of some cultural (ethnic) group, sometimes more than one. Most such groups feel—to varying degrees of intensity—that their way of life, their foods, dress, habits, beliefs, values, and so forth, are superior to those of other groups.

Ethnicity unrelated to biology

The most significant quality of ethnicity is the fact that it is unrelated to biology and can be flexible and transformable. People everywhere can change or enhance their ethnicity by learning about or assimilating into another culture. American society well illustrates these facts, consisting as it does of groups of people from hundreds of different world cultures who have acquired some aspects of American culture and now participate in a common sense of ethnic identity with other Americans.

Ethnic identity is acquired, and ethnic features are learned forms of behaviour. Race, on the other hand, is a form of identity that is perceived as innate and unalterable. Ethnicity may be transient and even superficial. Race is thought to be profound and grounded in biological realities. Ethnocentrism is based in a belief in the superiority of one's own culture over others, and it too may be transient and superficial. Racism is the belief in and promotion of the racial worldview described above. Ethnocentrism holds skin colour and other physical features to be irrelevant as long as one is a member of the same culture, or becomes so. The racial worldview holds that, regardless of behaviour or cultural similarities, a member of an inferior race (who is usually perceived to be so by means of physical features), can never be accepted. Race is an invented, fictional form of identity; ethnicity is based on the reality of cultural similarities and differences and the interests that they represent. That race is a social invention can be demonstrated by an examination of the history of the idea of race as experienced in the English colonies.

The history of the idea of race

Race as a categorizing term referring to human beings was first used in the English language in the late 16th century. Until the 18th century, it had a generalized meaning similar to other classifying terms such as type, sort, or kind. Occasional literature of Shakespeare's time referred to a "race of saints," or "a race of bishops." Some historians have speculated that the English learned the use of the term from the Spanish, with whom they had had trading relationships and, often, major conflicts. The Spanish term *raza* derives from the breeding of animals but began to include humans during the 17th century and reflected social divisions both in Spain and in their New World colonies. By the late 18th century, race was widely used for sorting and ranking the peoples in the English colonies—Europeans who saw themselves as free people, Amerindians who had been conquered, and Africans who were being brought in as slave labour—and this usage continues today.

The peoples conquered and enslaved were physically different from western and northern Europeans, but such differences were not the sole cause for the construction of racial categories. The English had had a long history of separating themselves from others and treating foreigners, such as the Irish, as alien "others." By the 17th century, their policies and practices in Ireland had led to an image of the Irish as "savages" who were incapable of being civilized. Proposals to conquer the Irish, take over their lands, and use the native peoples as forced labour failed largely because of Irish resistance. It was then that many Englishmen turned to the idea of colonizing the New World. Their attitudes toward the Irish set precedents for how they were to treat the New World Indians and, later, Africans.

The English attitude toward the Irish

THE PROBLEM OF LABOUR IN THE NEW WORLD

One of the greatest problems faced by settlers in the New World, particularly in the southern colonies, was the shortage of labour. Within a few decades after the settlement of Jamestown, planters had established indentured servitude as the main form of labour. Under this system, young men (and some women) worked for masters, to whom they were indebted for their transportation, normally for a period of four to seven years. They were paid no wages, received only minimal upkeep, and often were treated brutally.

By the mid-17th century, a wealthy few had encumbered virtually all lands not under Indian control and were attempting to work these lands using indentured servants. The working poor and those eventually freed from servitude had little on which to survive, and their dissatisfaction with the inequities of colonial society led to riots and numerous threats of revolt. After 1619, this group of poor servants included many Africans and their descendants, some of whom had had experience in the Spanish and Portuguese colonies, where slave labour was widely used.

The social position of Africans in the early colonies has been a source of considerable debate. Some scholars have argued that they were separated from European servants and treated differently from the beginning. Later historians, however, have shown that there was no such uniformity in the treatment of Africans. Records indicate that many Africans and their descendants were set free after their periods of servitude. They were able to purchase land and even bought servants and slaves of their own. Some African men became wealthy tradesmen, craftsmen, or farmers, and their skills were widely recognized. They voted, appeared in courts, engaged in business and commercial dealings, and exercised all the civil rights of other free men. Some free Africans intermarried, and their children suffered little or no special discrimination. Other Africans were poor and lived with other poor men and women; blacks and whites worked together, drank together, ate together, and frequently ran away together from intolerable conditions. Moreover, the poor of all colours protested together against the policies of the government (at least 25 percent of the rebels in Bacon's Rebellion were blacks, both servants and freedmen). The social position of

Africans and their descendants for the first six or seven decades of American history seems to have been open and fluid and not initially overcast with an ideology of inequality or inferiority.

The diminishing of labour from England

Toward the end of the 17th century, labour from England began to diminish, and the colonies were faced with two major dilemmas. One was how to maintain control over the restless poor and the freedmen who seemed intent on the violent overthrow of the colony's leaders. There had been several incidents that had threatened the leadership of the fragile colonies. Nathaniel Bacon's rebellion in Virginia in 1676 was a high point in the caustic relations between the planters and leaders of the colony and the impoverished workers. Although that rebellion failed, discontent continued to be expressed in riots, destruction of property, and other forms of social violence.

The second dilemma was how to obtain a controllable labour force as cheaply as possible. Tobacco was the chief source of wealth, and its production was labour-intensive. The colonial leaders found a single solution to both problems—they would divide the restless poor into categories reflecting their origins and institute a system of permanent slavery for Africans, the most vulnerable of the groups.

THE ENSLAVEMENT OF AFRICANS

Between 1660 and 1690, leaders of the Virginia colony began to establish practices that provided or sanctioned differential treatment for freed servants whose origins were in Europe. They conscripted poor whites, with whom they had never had interests in common, into the category of free men and made land, tools, animals, and other resources available to them. African Americans and Africans, mulattoes, and Indians, regardless of their cultural similarities or differences, were homogenized into a category separate from whites. Historical records show that the Virginia Assembly went to great extremes not only to purposely divide Europeans from Indians and Africans but to promote contempt on the part of whites against Negroes. Recognizing the vulnerability of African labour, colonial leaders passed laws that increasingly bound Africans and their children permanently as servants and, eventually, as slaves. White servants had the protection of English laws, and their mistreatment was criticized abroad. Africans, however, had no such recourse. By 1723 even free African Americans, descendants of several generations then of free people, were prohibited from voting. Colonial leaders thus began using the physical differences among the population to structure an in-egalitarian society. In the island colonies of Barbados and Jamaica, the numbers of Irish and Indian slaves also declined, and planters turned increasingly to Africans. Southern planters, who were in regular communication with these island communities, brought in large numbers of Africans during the 18th century and developed their slave practices rapidly.

Christianity provided an early rationalization for permanent enslavement: Africans were heathens and slaves in their own lands; under English slavery, their souls would be saved. The underlying reality was that their labour was needed to produce wealth for the colonies and for England's upper classes. During these early decades, many Englishmen considered the Africans to be civilized. Unlike the Indians, whom they called "savages" and who were largely nomadic hunter-gatherers, the English knew the Africans in the colonies as sophisticated cultivators who understood how to grow foods and other crops in tropical soils. In this they surpassed the Irish who had been enslaved on plantations in the Caribbean; with no tradition of agriculture in tropical habitats, the Irish failed as producers of necessary goods. Some Africans were skilled metalworkers, knowledgeable about smelting, blacksmithing, and toolmaking. Many others were skilled in woodworking, weaving, pottery and rope making, leather work, brick making, thatching, and other crafts.

The skills of Africans

Two additional factors made Africans more desirable as slaves: Africans were immune to Old World diseases, which caused Indians to sicken and die; and, most important, Africans had nowhere to run, unlike the Indians—who could escape from slavery into their own familiar territory. The Irish, who were also in an alien land, were perceived as unruly and violent. When they escaped, they often joined their fellow Catholics, the Spanish and the French, in conspiracies against the English.

Thus Africans became the preferred slaves, not because of their physical differences, although such differences became increasingly important, but because they had the knowledge and skills that made it possible to put them to work immediately. They were not Christian, they were vulnerable, with no legal or moral opposition to their enslavement, and, once transported to the New World, they had few options. Moreover, the supply of Africans increased as the costs of transporting them fell, and English merchants became directly involved in the slave trade.

HUMAN RIGHTS VERSUS PROPERTY RIGHTS

Chattel slavery was not established without its critics. From the beginning, many Englishmen condemned the presence of slavery in English territories. For several hundred years, trends in English culture had been toward the expansion of human rights and the recognition of individual liberty. Slavery, many argued, was antithetical to a free society and subversive of Christian values.

Throughout the 18th century, however, another powerful value in English culture, the sanctity of property and property rights, came to dominate colonial concerns. When faced with growing antislavery arguments, planters in the southern colonies and Caribbean islands, where slavery was bringing great wealth, turned to the argument that slaves were property and that the rights of slave owners to their property were by law unquestionable and inviolable. The laws and court decisions reflected the belief that the property rights of slave owners should take precedence over the human rights of slaves.

The requisite for dehumanization

Historians concur that the emphasis on the slave as property was a requisite for dehumanizing the Africans. Says Philip D. Morgan, "The only effective way to justify slavery was to exclude its victims from the community of man." Attitudes and beliefs about all Africans began to harden as slavery became more deeply entrenched in the colonies. A focus on the physical differences of Africans expanded as new justifications for slavery were needed, especially during the Revolutionary War period, when the rallying cry of freedom from oppression seemed particularly hypocritical. Many learned men on both sides of the Atlantic disputed the moral rightness of slavery. Opponents argued that a society of free men working for wages would be better producers of goods and services. But proslavery forces, which included some of the wealthiest men in America and England, soon posed what they came to believe was an unassailable argument for keeping blacks enslaved: the idea of black inferiority.

BUILDING THE MYTH OF BLACK INFERIORITY

A number of 18th-century political and intellectual leaders publicly asserted that Africans were naturally inferior and that they were indeed best suited for slavery. A few intellectuals revived an older image of all living things, the *scala naturae* (Latin: "scale of nature"), or Great Chain of Being, to demonstrate that nature or God had made men unequal. This ancient hierarchical paradigm—encompassing all living creatures, starting with the simplest organisms and reaching to humans, angels, and ultimately to God—became for the advocates of slavery a perfect reflection of the realities of inequality that they had created. The physical differences of blacks and Indians became the symbols or markers of their status. It was during these times that the term *race* became widely used to denote the ranking and inequality of these peoples—in other words, their placement on the chain of being.

Beginning in the late 18th century, differences among the races became magnified and exaggerated in the public mind. Hundreds of battles with Indians had pushed these populations westward to the frontiers or relegated them increasingly to reservation lands. A widely accepted stereotype had grown that the Indian race was weak and would succumb to the advances of white civilization so that these native peoples were no longer much of a problem. Their deaths from disease and warfare were seen as a testament to the inevitable demise of the Indian.

The fear of revolt

Racial stereotyping of Africans was magnified by the Haitian rebellion of 1791. This heightened the American fear of slave revolts and retaliation, causing greater restrictions and ever harsher and more degrading treatment. Grotesque descriptions of the low-status races, blacks and Indians, were widely publicized, and they helped foster fear and loathing. This negative stereotyping of low-status racial populations was ever present in the public consciousness, and it affected relations among all people.

By the mid-19th century, race in the popular mind had taken on a meaning equivalent to species-level distinctions, at least for differences between blacks and whites. The ideology of separateness that this proclaimed difference implied was soon transformed into social policy. Although legal slavery in the United States ended in 1865 with the passage of the 13th Amendment to the Constitution, the ideology of race continued as a new and major form of social differentiation in both American and British society. The black codes of the 1860s and the Jim Crow laws of the 1890s were passed in the United States to legitimate the social philosophy of racism. More laws were enacted to prevent intermarriage and intermating, and the segregation of public facilities was established by law, especially in the South. The country's low-paying, dirty, and demeaning jobs were relegated to "the Negro" as he was seen fit for only such tasks. Supreme Court decisions, such as the Dred Scott case of 1857, made clear that Negroes were not and could not be citizens of the United States. They were to be excluded from the social community of whites, but not from the production of their wealth. The Supreme Court decision in *Plessy* v. *Ferguson* (1896), which permitted "separate but equal" facilities, guaranteed that the racial worldview, with its elements of separateness and exaggerated difference, would continue to flourish.

IMMIGRATION AND THE RACIAL WORLDVIEW

In the 1860s, when Chinese labourers immigrated to the United States to build the Central Pacific Railroad, a new population with both physical and cultural differences had to be accommodated within the racial worldview. While industrial employers were eager to get this new and cheap labour, the ordinary white public was stirred to anger by the presence of this "yellow peril." Political party caucuses, labour unions, and other organizations railed against the immigration of yet another "inferior race." Newspapers condemned the policies of employers, and even church leaders decried the entrance of these aliens into what was seen as a land for whites only. So hostile was the opposition that in 1882 Congress finally passed the Chinese Exclusion Act.

The Chinese Exclusion Act

The large migrations from southern and eastern Europe that started in the 1880s required the reassessments of other new people and their incorporation into the racial ranking system. Old-stock Americans (English, Dutch, German, Scandinavian) were horrified at the onslaught of large numbers of people speaking Italian, Greek, Hungarian, Russian, and other "foreign" languages. They held that such "races" could not be assimilated into "Anglo-Saxon" culture, and policies and practices had to be put into place to separate them from the mainstream.

Despite much opposition, these European groups soon lost their inferior race status, and within a few generations their descendants not only assimilated into the "white" category, they also incorporated the dominant racial worldview. More than half the ancestors of late 20th-century American whites immigrated to the United States during the period 1880–1930. The "white" racial category was constructed flexibly enough to enclose even those who could not claim an Anglo-Saxon background.

During the 19th century, the idea of race was diffused throughout the European colonial systems, reinforced by the fact that the peoples conquered and colonized by western European powers were also physically different. Such conquests buttressed the idea of European racial superiority. The racial worldview with its tenets regarding the limited capacities of inferior races was employed to justify the extermination of peoples, including the Tasmanians, most of the Maoris, and many indigenous Australians. It was an essential ingredient in the colonial policies and practices of the British in India and Southeast Asia and, later, in Africa. Numerous British writers of the 19th century, such as Rudyard Kipling, openly declared that the British were a superior race destined to rule the world.

Legitimating the racial worldview

ENLIGHTENMENT PHILOSOPHERS AND TAXONOMISTS

The development of the idea and ideology of race coincided with the rise of science in American and European cultures. Much of the inspiration for the growth of science has been credited to the period known as the Enlightenment that spanned most of the 18th century. Many early Enlightenment writers believed in the power of education and fostered very liberal ideals about the potentiality of all peoples, even "savages," for human progress. Yet, later in the century, some of the earliest assertions about the natural inferiority of Africans were published. Major proponents of the ideology of race inequality were the German philosopher Immanuel Kant, the French philosopher Voltaire, the Scottish philosopher and historian David Hume, and the influential American political philosopher Thomas Jefferson. These writers expressed negative opinions about Africans and other "primitives" based on purely subjective impressions or materials gained from secondary sources, such as travelers, missionaries, and explorers. Thus the philosophers expressed the common attitudes of this period.

During the same period, influenced by taxonomic activities of botanists and biologists that had begun in the 17th century, other European scholars and scientists were involved in the serious work of identifying the different kinds of human groups increasingly discovered around the world. The work of the naturalists and systematists brought attention to the significance of classifying all peoples into "natural" groupings, as had been done with other flora and fauna. Although many learned men were involved in this enterprise, it was the classifications developed by the Swedish botanist Carolus Linnaeus and the German physiologist Johann Friedrich Blumenbach that have provided the models for modern racial classifications.

Linnaeus and Blumenbach

SCIENTIFIC CLASSIFICATIONS OF RACE

In publications issued from 1735 to 1759, Linnaeus classified all of the then-known animal forms. He included humans with the primates and established the use of both genus and species terms for identification of all animals. For the human species, he introduced the still-current scientific name *Homo sapiens.* He listed four major subdivisions of this species, *H. americanus, H. africanus, H. europaeus,* and *H. asiaticus.* Such was the nature of knowledge at the time that Linnaeus also included the categories *H. monstrosus* (which included many exotic peoples) and *H. ferus* ("wild man"), an indication that some of his categories were based on tall tales and travelers' myths.

Blumenbach divided humankind into five "varieties" and noted that clear lines of distinction could not be drawn between them as they tended to blend "insensibly" into one another. His five categories included American, Malay, Ethiopian, Mongolian, and Caucasian. (He had chosen the term *Caucasian* to represent the Europeans because a skull from the Caucasus Mountains of Russia was in his opinion the most beautiful.) These terms were still used by many scientists of the early 20th century, and most continue today as major designations of the world's peoples.

These classifications not only rendered human groups as part of nature but also gave them concreteness, rigidity, and permanence. Moreover, some descriptions, especially those of Linnaeus, included statements about the temperament and customs of various peoples that had nothing to do with biophysical features but were forms of learned behaviour that are now known as "culture." That cultural behaviour and physical characteristics were conflated by these 18th-century writers reflects both their ethnocentrism and the limited scientific knowledge of the time.

THE INSTITUTIONALIZING OF RACE

Slavery by nature creates social distance between masters and slaves, and intellectuals are commonly called upon to

affirm and justify such distinctions. As learned men began to write a great deal about the "racial" populations of the New World, Indians and Negroes were increasingly projected as alien. In this way did the Enlightenment thinkers help pro-slavery interests place responsibility for slavery in the "inferior" victims themselves.

Would-be "scientific" writings about the distinctiveness of blacks and Indians commenced late in the 18th century in tandem with exaggerated popular beliefs, and writings of this type continued on into the 20th century. The European world sought to justify not only the institution of slavery but also its increasingly brutal marginalization of all non-European peoples, slave or free. Science became the vehicle through which the delineation of races was confirmed, and scientists in Europe and America provided the arguments and evidence to document the inequality of non-Europeans.

"Science" as vehicle

About the turn of the 19th century, some scholars advanced the idea that the Negro (and perhaps the Indian) was a separate species from "normal" men (white and Christian), an idea that had been introduced and occasionally expressed in the 18th century but that had drawn little attention. This revived notion held that the "inferior races" had been created at a different time than Adam and Eve, who were the progenitors of the white race. Although the idea of multiple creations contradicted both the well-known definition of species in terms of reproductively isolated populations and the biblical description of Creation, it is clear that in the public mind the transformation from race to species-level difference had already evolved. In the courts, statehouses, assemblies, churches, and throughout American institutions, race became institutionalized as the premier source, and the causal agent, of all human differences.

TRANSFORMING "RACE" INTO "SPECIES"

One of those whose direct experience of African slaves and assessment of them was given great weight was Edward Long (1734–1813), a former plantation owner and jurist in Jamaica. In a book entitled *The History of Jamaica* (1774), Long asserted that "the Negro" was "void of genius" and "incapable" of civilization; indeed, he was so far inferior as to constitute a separate species of mankind. Long's work was published as a defense of slavery during a period of rising antislavery sentiment. Its greatest influence came during and after the American Revolutionary War (1775–83), when some southern Americans started freeing their slaves and moving north. Long's writings, published in popular magazines, were widely read in the United States during the last decade of the 18th century.

In 1799 Charles White, a Manchester physician, published the earliest proper "scientific" study of human races. He described each racial category in physical terms, identifying what he thought were differences in the head, feet, arms, complexion, skin colour, hair texture, and susceptibility to disease. White actually measured the body parts of a group of Negroes and whites, lending the semblance of "hard" science to his conclusions. He not only advocated a gradation of the races, but he provided support for the speculation that the Negro, the American Indian, some Asiatic tribes, and Europeans were of different species. His explanation for the presumed savagery of Africans was they had degenerated from the pure and idyllic circumstances provided in the Garden of Eden, while Europeans had made advances toward civilization.

Such works as those of Long and White initiated a debate among scholars and scientists that had long-range implications for European attitudes toward human differences. The issue, as expressed by mid-19th-century scientists, was "the Negro's place in nature"—that is, whether "the Negro" was human like Europeans or a separate species nearer to the ape.

Morton's measurements

Samuel Morton, a Philadelphia physician and founder of the field of craniometry, collected skulls from around the world and developed techniques for measuring them. He thought he could identify racial differences among these skulls. After developing means of measuring the internal capacity of the skull, he concluded that Negroes had smaller brains than whites, with Indian brains intermediate between the two. Because brain size had long been correlated with intelligence in both the popular mind and science, Morton's findings seemed to confirm that Negroes were also less intelligent than whites. In publications of 1839 and 1844, he produced his results, identifying Native Americans as a separate race from Asians and arguing from his Egyptian materials that these ancient peoples were not Negroes. His findings magnified and exaggerated the differences among racial populations, imposing meaning on the differences that led to the conclusion that they were separate species.

Morton soon became the centre of a network of scholars and scientists who advocated multiple creations (polygeny) and thus contradicted the long-established biblical view of one single creation from which all humans descended (monogeny). The most influential of the scientists involved in this debate was Louis Agassiz, who accepted a position at Harvard University and revolutionized the field of natural science. Agassiz converted from monogenism to polygenism after moving to the United States from Switzerland in 1846. It was then that he saw Negroes for the first time. He was also impressed with Morton's work with skulls, and eventually he became the most important advocate of polygenism, conveying it in public lectures and to generations of students, many of whom took leading intellectual roles in American society.

One result of the mid-19th-century concern with documenting racial distinctions by means of body measurements was the establishment of the "scientific" enterprise of anthropometry. During the Civil War, the U.S. Sanitary Commission and the provost marshall general's office collected data on the physical condition of military conscripts and volunteers in the army, navy, and marines. Using anthropometric techniques, they produced massive tables of quantitative measurements of the body dimensions of tens of thousands of whites, Negroes, mulattoes, and Indians. Scientists interpreted the data in a way that strengthened the argument that races were fundamentally distinct and that confirmed that blacks, Indians, and mulattoes were inferior to whites. Anthropometry flourished as a major scientific method for demonstrating race differences well into the 20th century.

THE FALSE ASSUMPTIONS OF ANTHROPOMETRY

While scholars continued to debate "the Negro's place in nature," the debate over multiple or single origins receded after 1859, when the publication of Charles Darwin's theory of evolution led to a more dynamic perspective on species. Evolution produced new arguments on the causes of the Negro's innate condition; the central problem became whether Negroes evolved before or after whites. By the 1860s, the Negro's primitiveness was putative and unquestioned. "The Negro," in fact, had become the new savage, displacing Indians and Irishmen, and the ideology proclaimed that his savagery was both intrinsic and immutable.

The use of metrical descriptions, while they seemed objective and scientific, fostered typological conceptions of human group differences. From massive quantitative measurements, experts computed averages, means, and standard deviations from which they developed statistical profiles of each racial population. These profiles were thought to represent the type characteristics of each race expressed in what seemed to be impeccable scientific language. When statistical profiles of one group were compared with those of others, one could theoretically determine the degree of their racial differences.

Type characteristics

The activities of typologists carried a number of false assumptions about the physical characteristics of races. One was that racial characteristics did not change from one generation to another, meaning that averages of measurements such as body height would remain the same in the next generations. Another false assumption was that statistical averages could accurately represent huge populations, when the averaging itself obliterated all the variability within those populations.

Expressed alongside existing myths and popular racial stereotypes, these measurements inevitably strengthened the assumption that some races were "pure" and some not

so "pure." Scholars argued that all the major races were originally pure and that some races represented the historical mixing of two or more races in the past. "Racial types" were conceived as representing populations with certain inherited morphological features that were originally characteristic of the race; every member of a race thus retained such traits. These beliefs attempted to validate the image of races as internally homogeneous and biologically discrete, having no overlapping features with other races.

The beginning decline of "race" in science

THE INFLUENCE OF FRANZ BOAS

Typological thinking about race, however, was soon contradicted by the works of some early 20th-century anthropologists. Franz Boas, for example, published studies that showed that morphological characteristics varied from generation to generation in the same population, that skeletal material such as the cranium was malleable and subject to external influences, and that metrical averages in a given population changed in succeeding generations.

Boas and the early anthropologists trained in the United States recognized that the popular conception of race linked, and thus confused, biology with language and culture. They began to advocate the separation of "race," as purely a biological phenomenon, from behaviour and language, denying a relationship between physical traits and the languages and cultures that people carry.

Though their arguments had little impact on the public at the time, these scholars initiated a new way of thinking about human differences. The separation of culture and language, which are learned behaviours, from biological traits that are physically inherited became a major tenet of anthropology. As the discipline grew and spread by means of scholarship and academic training, public understanding and recognition of this fundamental truth increased. Yet the idea of a hereditary basis for human behaviour remained a stubborn element of both popular and scientific thought.

MENDELIAN HEREDITY AND THE DEVELOPMENT OF BLOOD GROUP SYSTEMS

In 1900, after the rediscovery of Gregor Mendel's experiments dealing with heredity, scientists began to focus greater attention on genes and chromosomes. Their objective was to ascertain the hereditary basis for numerous physical traits. Once the ABO blood group system was discovered and was shown to follow the pattern of Mendelian heredity, other systems—the MN system, the Rhesus system, and many others—soon followed. Experts thought that at last they had found genetic features that, because they are inherited and not susceptible to environmental influences, could be used to identify races. By the 1960s and '70s, scientists were writing about racial groups as populations that differed from one another not in absolute features but in the frequencies of expression of genes that all populations share. It was expected that each race, and each population within each race, would have frequencies of certain ascertainable genes that would mark them off from other races.

Information on blood groups was taken from large numbers of populations, but when scientists tried to show a correlation of blood group patterns with the conventional races, they found none. While populations differed in their blood group patterns, in such features as the frequencies of A, B, and O types, no evidence was found to document race distinctions. As knowledge of human heredity expanded, other genetic markers of difference were sought, but these also failed to neatly separate humanity into races. Most human physical variations are expressed in subtle gradations over wide geographic space, not in abrupt disjunctions from one "race" to another. Moreover, not all groups within a large "geographic race" share the same patterns of genetic features. The internal variations within races have proved to be greater than those between races. Most important, physical, or phenotypic, features determined by DNA are inherited independently of one another, further frustrating attempts to describe race differences in genetic terms.

No evidence of race distinctions

"Race" and intelligence

Anthropometric measurements did not provide any data to prove group superiority or inferiority. As various fields of study emerged in the late 19th century, some scholars began to focus on mental traits as a means to examine and describe human differences. Psychology as a growing field began developing its own programmatic interests in discovering race differences.

In the 1890s, the psychologist Alfred Binet began testing the mental abilities of French schoolchildren to ascertain how children learned and to help those who had trouble learning. Binet did not call his test an intelligence test, and its purpose was not to divide French schoolchildren into hierarchical groups. But with these tests, a new mechanism was born that would provide powerful support to those who held beliefs in racial differences in intelligence.

Psychologists in the United States very quickly adopted Binet's tests and modified them for American use. More than that, they reinterpreted the results to be clear evidence of innate intelligence. Lewis Terman and his colleagues at Stanford University developed the Stanford-Binet IQ (intelligence quotient) test, which set the standard for similar tests produced by other American psychologists.

IQ tests began to be administered in great number during the second decade of the 20th century. The influences of hereditarian beliefs and the power of the racial worldview had conditioned Americans to believe that intelligence was inherited and permanent and that no external influences could affect it. Indeed, heredity was thought to determine a person's or a people's place in life and their success or failure. Americans came to employ IQ tests more than any other nation. A major reason for this was that the tests tended to confirm the expectations of white Americans; on average, Negroes did less well than whites on IQ tests. But the tests also revealed that the disadvantaged of all races do worse on IQ tests than do the privileged. Such findings were compatible with the beliefs of large numbers of Americans who had come to accept unqualified biological determinism.

The popularity of IQ tests

Opponents of IQ tests and their interpretations argued that intelligence had not been clearly defined, that experts did not agree on its definition, and that there were many different types of intelligence that cannot be measured. They also called attention to the many discrepancies and contradictions of the tests. One of the first examples of empirical evidence against the "innate intelligence" arguments was the revelation by psychologist Otto Klineberg in the 1930s that Negroes in four northern states did better on average than whites in the four southern states where expenditures on education were lowest. Klineberg's analysis pointed to a direct correlation between income and social class and performance on IQ tests. Further evidence indicated that students with the best primary education and greater cultural experiences always did better on such tests. Experts thus argued that such tests are culture-bound—that is, they reflect and measure the cultural experiences and knowledge of those who take the tests and their levels of education and training. Few would deny that African Americans and Native Americans have long had a much narrower and more restricted experience of American culture and a far inferior education.

Hereditarian ideology and European constructions of race

HEREDITARY STATUSES VERSUS THE RISE OF INDIVIDUALISM

Inheritance as the basis of individual social position is an ancient tenet of human history, extending to some point after the beginnings of agriculture (about 8000–10,000 BCE). Expressions of it are found throughout the world in kinship-based societies where genealogical links determine an individual's status, rights, and obligations. Wills and testaments capture this principle, and caste systems, such as that of India, reflect the expression of another form of this principle, buttressed by religious beliefs. Arguments for the divine right of kings and succession laws in European societies mirrored deep values of hereditary status.

But many trends in European culture history over the 18th and 19th centuries contradicted hereditarian customs. These included growing ideas regarding individual rights, including the right to accumulate private property, and free wage labour. For their descendants in America, the limitations of hereditary status were antithetical to the values of individual freedom, at least freedom for those of European descent.

Reflecting and promoting these values were the works of some of the Enlightenment writers and philosophers, including Voltaire, Jean-Jacques Rousseau, John Locke, and Montesquieu. Their writings had a greater impact on Americans than on their compatriots. Their advocacy of human freedom and the minimal intrusion of government was uniquely interpreted by Americans.

Class and the age of empire building

European societies had long been structured into class divisions that had a strong hereditary basis, but the gulf between those who benefited from overseas trade and the impoverished masses who competed for low-paying jobs or survived without work in the gutters of towns and cities widened dramatically during the age of empire building. In France the dissatisfaction of the masses erupted periodically, reaching a peak in the French Revolution of 1789, which overthrew the Bourbon monarch and brought Napoleon I to power.

As early as the turn of the 18th century, some intellectuals were concerned with these seething class conflicts that occasionally burst forth into violence in France. Henri de Boulainvilliers, whose works were published in the 1720s and '30s, put forth an argument designed to justify the dominance of the aristocratic classes in France. He maintained that the noble classes were originally Germanic Franks who conquered the inferior Gauls, Romans, and others and established themselves as the ruling class. The Franks derived their superiority from German forebears, who were a proud, freedom-loving people with democratic institutions, pure laws, and monogamous marriage. They were great warriors, disciplined and courageous, and they ruled by the right of might. According to Boulainvilliers, they carried and preserved their superiority in their blood. With this argument, hereditarian ideology intruded into the consciousness of France's elite class and synthesized with a growing ideology of "race" as the causal explanation for historical events.

THE GERMANIC MYTH AND ENGLISH CONSTRUCTION OF AN ANGLO-SAXON PAST

In England, from the time that Henry VIII broke with the Roman Catholic church and as Protestant sects emerged on the horizon, historians, politicians, and philosophers had been wrestling with the creation of a new English identity. The English sought their new identity in the myths and heroics of the past and strove to create an image of antiquity that would rival those of other great civilizations. They created a myth of an Anglo-Saxon people, distinguished from the Vikings, Picts, Celts, Romans, Normans, and others who had inhabited English territory. In their histories, the Anglo-Saxons were a freedom-loving people who had advanced political institutions, an early form of representative government, and a pure religion long before the Norman Conquest. Although in part the English were concerned about the identification and preservation of ancient institutions to justify the distinctiveness of their political and ecclesiastical structures, they also wanted to establish and glorify a distinguished ancestry. The English, too, turned toward the German tribes and a "racial" ideology on which to base their claims of superiority.

The *Germania* of Tacitus

The English scholars and Boulainvilliers derived their depictions of the Germans and their arguments from a common source, the works of Tacitus, a Roman historian born in the middle of the 1st century AD. At the end of the 1st century, Tacitus had published the *Germania,* a study of the German tribes to the north of Rome. It is the first, and most comprehensive, ethnographic study compiled in the ancient world and remains today a good description of a people seen at that time as barbarians.

Tacitus idealized the simple, unadulterated lives of the German tribes and contrasted what he saw as their positive cultural features with the decadence and decline of the Romans. The German tribes were indeed the first noble savages of the Western world. Tacitus clearly sought to provide a moral lesson about the corruption and decline of civilizations in contrast to the virtues and moral uprightness of simple societies. Little could he have anticipated that his descriptions of a simple tribal people, written for 2nd-century Romans, would form one of the bases for a powerful theory of racial superiority that dominated the Western world during the 19th and 20th centuries.

None of the writers harking back to the German tribes for a depiction of good government and pure institutions noted any of the negative or unsavory characterizations that Tacitus also detailed in the *Germania.* Among other things, he claimed that the Germans were intensely warlike; they hated peace and despised work; when not fighting—and they loved fighting, even among themselves—they idled away their time or slept. They had a passion for gambling and drinking, and they gave blind obedience to their chiefs.

The Germanic myth flourished and spread. Boulainvilliers was widely read in England and by segments of the intellectual classes in Germany and France. By the mid- to late 18th century, the English version of the Germanic myth—Anglo-Saxonism—had been transformed from an idea of superior institutions into a doctrine of English biological superiority. The French version remained a competing idea validating social class interests in that nation, and, with the defeat of Napoleon and the restoration of the monarchy after 1815, it was revived by those political forces that believed in the permanence of the unequal social hierarchy. It would grow and penetrate into many other areas, notably the modern German nation itself.

Anglo-Saxonism

GOBINEAU'S ESSAY ON THE INEQUALITY OF HUMAN RACES

The most important promoter of racial ideology in Europe during the mid-19th century was Joseph-Arthur, comte de Gobineau, who had an almost incalculable effect on late 19th-century social theory. Published in 1853–55, his *Essay on the Inequality of Human Races* was widely read, embellished, and publicized by many different kinds of writers. He imported some of his arguments from the polygenists, especially the American Samuel Morton. Gobineau claimed that the civilizations established by the three major races of the world (white, black, and yellow) were all products of the white races and that no civilizations could emerge without their cooperation. The purest of the white races were the Aryans. When Aryans dilute their blood by intermarriage with lower races, they help to bring about the decline of their civilization.

Following Boulainvilliers, Gobineau advanced the notion that France was composed of three separate races—the Nordics, the Alpines, and the Mediterraneans—that corresponded to France's class structure. Each race had distinct mental and physical characteristics; they differed in character and natural abilities, such as leadership, economic resourcefulness, and creativity, and in morality and aesthetic sensibilities. The tall, blond Nordics, who were descendants of the ancient Germanic tribes, were the intellectuals and leaders. Alpines, who were brunet and intermediate in size between Nordics and Mediterraneans, were the peasants and workers; they required the leadership of Nordics. The shorter, darker Mediterraneans he considered a decadent and degenerate product of the mixture of unlike races; to Gobineau, they were "nigridized" and "semitized."

Americans of this period were among Gobineau's greatest admirers; so were many Germans. The latter saw in his works a formula for unifying the German peoples and ultimately proclaiming their superiority. Many proponents of German nationalism became activists and organized political societies to advance their goals. They developed a new dogma of "Aryanism" that was to expand and become the foundation for Nazi race theories in the 20th century.

Houston Stewart Chamberlain

Gobineau was befriended by the great composer Richard Wagner, who was a major advocate of racial ideology during the late 19th century. It was Wagner's future son-in-law Houston Stewart Chamberlain, writing at the end of the 19th century, who glorified the virtues of the Germans as the superrace. In a long book entitled *The Foundations of*

the Nineteenth Century, Chamberlain explained the history of the entire 19th century—with its European conquests, dominance, colonialism, and exploitation—as a product of the great accomplishments of the German people. Though English-born, Chamberlain had a fanatical attraction to all things German and an equally fanatic hatred of the Jews. He believed Jesus was a Teuton, not a Jew, and argued that all Jews had as part of their racial character a moral defect. Fueled by rising anti-Semitism in Europe, race ideology facilitated the manufacture of an image of the Jews as a distinct and inferior race. Chamberlain's speculations about the greatness of the Germans and their destiny were avidly consumed by many in Germany, especially young men such as Adolf Hitler and his companions in the National Socialist Party.

As this history shows, European peoples took the constituent components of the ideology of race and molded them to the exigencies of their particular political and economic circumstances, applying them to their own ethnic and class conflicts. Race thus emerged as a powerful denoter of unbridgeable differences that could be applied to any circumstances, particularly of ethnic conflict. The German interpretation of race eventually took the ideology to its logical extreme, the belief that a "superior race" has the right to eliminate "inferior races."

GALTON AND SPENCER

Hereditarian ideology also flourished in late 19th-century England. Two major writers and proselytizers of the idea of the innate racial superiority of the upper classes were Francis Galton and Herbert Spencer. Galton wrote books with titles such as *Hereditary Genius* (1869), in which he showed that a disproportionate number of the great men of England, the military leaders, philosophers, scientists, and artists came from the small upper-class stratum. Spencer incorporated the themes of biological evolution and social progress into a grand universal scheme. Antedating Darwin, he introduced the ideas of competition, the struggle for existence, and the survival of the fittest. His "fittest" were the socially and economically most successful not only among groups but within societies. The "savage" or inferior races of men were clearly the unfit and would soon die out. For this reason, Spencer advocated that governments eschew policies that helped the poor; he was against all charities, child-labour laws, women's rights, and education for the poor and uncivilized. Such actions, he claimed, interfered with the laws of natural evolution; these beliefs became known as social Darwinism.

The United States a ready market

The hereditarian ideologies of European writers in general found a ready market for such ideas among all those nations involved in empire-building. In the United States these ideas paralleled and strengthened the racial ideology then deeply embedded in American values and thought. They had a synergistic effect on ideas of hereditary determinism in many aspects of American life and furthered the acceptance and implementation of IQ tests as an accurate measure of innate human ability.

"Race" ideologies in the non-Western world

EUROPEAN CONQUEST AND THE CLASSIFICATION OF THE CONQUERED

As they were constructing their own racial identities internally, western European nations were also colonizing most of what has been called, in more recent times, the Third World, in Asia and Africa. Since all of the colonized and subordinated people differed physically from Europeans, the colonizers automatically applied racial categories to them and initiated a long history of discussions about how such populations should be classified. There is a very wide variety of physical variations among Third World people, and subjective impressions generated much scientific debate, particularly about which features were most useful for racial classification. Experts never reached agreement on such classifications, and some questions, such as how to classify indigenous Australians, were subjects of endless debate and never resolved.

The concept of race had become so deeply entrenched in American and European thought by the end of the 19th century that scholars and other learned people came to believe that the idea of race was universal. They searched for examples of race ideology among indigenous populations and reinterpreted the histories of these peoples in terms of Western conceptions of racial causation for all human achievements or lack thereof. Thus the so-called Aryan invasions of the Indian subcontinent between 1600 BC and about 600 BC were seen, and lauded by some, as an example of a "racial" conquest by a light-skinned race over darker peoples. The Aryans of ancient India (not to be confused with the Aryans of 20th-century Nazi ideology) were pastoralists who spread south into the Indian subcontinent and intermingled with sedentary peoples, such as the Dravidians, many of whom happened to be very dark-skinned as a result of their long adaptation to a hot tropical environment. Out of this fusion of cultures and peoples, modern Indian, or Hindu, civilization arose. Such conquests and syntheses of new cultural forms have taken place numerous times in human history even in areas where there was little or no difference in skin colour (as, for example, the westward movements of Mongols and Turkish peoples).

INDIA'S CASTE SYSTEM

India has a huge population encompassing many obvious physical variations, from light skins to some of the darkest in the world, from straight coarse hair to frizzled and crinkly hair, and a wide variety of facial features. In addition, the Hindu sociocultural system is divided into castes that are exclusive, hereditary, and endogamous. They are also ranked and unequal and thus appear to have many of the characteristics of "race." But the complex caste system is not based primarily on colour, as castes include people of all physical variations, nor is it based on a "scientific" ideology of superiority or inferiority. Colour variations in India, as elsewhere, are a product of natural selection in tropical and semitropical environments, of genetic drift among small populations, and of historical migrations and contact among peoples.

The basis of the caste system

Castes were, and are still, occupational groups as well as elements in a religious system that accords different values and different degrees of purity to different occupations. They also are the main regulators of marriage and inheritance rights. Some castes were originally small-scale tribal groups who were incorporated into the Hindu kingdoms. It has been noted that there are thousands of castes in India and many different ways of ranking them, including such cultural features as food taboos and sharing obligations, but none are based in skin colour or "race." Although some early 20th-century European scholars tried to divide the Indian and other Asian peoples into "races," their efforts were hindered not only by the complexity of physical variations in India, parts of Southeast Asia, and Melanesia but by the developing fields of science.

Caste discrimination has been outlawed in India today, although it remains deeply rooted in the cultures of ordinary people. Moreover, democratic values, individual rights, and the processes of industrialization have affected the more rigid social caste system of India and led in some areas to a blurring of caste boundaries and a decline in the importance of caste identity.

JAPAN'S MINORITY PEOPLES

A few ethnographic studies have suggested to some that a form of racial ideology may also have developed independently of the West in some traditional societies such as that of Japan, where various minority peoples, notably the *burakumin* (pejoratively called Eta) and the Ainu, have been victimized and exploited by the dominant society. Discrimination against such groups incorporates myths about their biological inferiority. Japanese folk beliefs attribute many unusual physical characteristics to the *burakumin,* but biological anthropologists have not been able to physically distinguish them from other Japanese. Prejudice against them and their segregation in society stems from their history as a caste of people who performed "unclean" tasks (butchering animals, disposing of corpses, etc.), a characteristic found in some other societies.

The Ainu

The Ainu, on the other hand, have many physical features that are more similar to Europeans than to Asians,

not only in their skin colour, but particularly in their abundance of body hair and their occidental eyes. Although they may have occupied much of Japan in the past, they are relegated today mainly to the northern island of Hokkaido. It is arguable whether the traditional ideology supporting Japanese attitudes toward these people reflects the features of the racial worldview described here. The same is true of Japanese attitudes toward other ethnic groups, such as Koreans. Extreme ethnocentrism has characterized many intergroup relations in the past.

Such intergroup hostilities always have a basis in cultural realities, in competition for land, for region-wide political power, or for the souls of people, as the history of most of the world's peoples in the past several thousand years has revealed. Mere variations in physical features have never been the sole cause of such enmity. And the belief systems have never been institutionalized by law or buttressed by religion and science.

"Race" and the reality of human physical variation

Scientists have known for many decades that there is little correlation between "race," used in its popular sense, and actual physical variations in the human species. In the United States, for example, the people identified as African Americans do not share a common set of physical characteristics. There is a greater range of skin colours, hair colours and textures, facial features, body sizes, and other physical traits in this category than in any other human aggregate identified as a single race. Features of African Americans vary from light skins, blue or gray eyes, and blond hair to dark skins, black eyes, and crinkly hair, and every range and combination of characteristics in between. American custom has long classified any person with known African ancestry as black, a social mandate often called the "one-drop rule." This principle not only attests to the arbitrary nature of black racial identity, but it was also presumed to keep those classified as racially "white" pure and untainted by the "blood" of low-status and inferior races. This rule has not applied to other "racial" mixtures, such as children born of white and Asian parents, although some of these children have suffered discrimination because of physical similarities to their lower-status parent. All of this gives clear evidence of the socially arbitrary nature of race categories in North America.

Other types of anomalies have frequently appeared in efforts to classify "racial" populations around the world. Whereas British scholars, for example, tend to separate East Indians into a separate racial category (during the colonial period, natives of India, Burma, Melanesia, and Australia were, and still are, called "blacks"), American scholars have usually included East Indians in the "Caucasian" category to differentiate them from American blacks. Light-skinned Indians usually from northern India have been accepted as "white," but Indians with very dark skin have sometimes experienced discrimination in the United States.

Since World War II, travel and immigration have greatly increased the contact of Western peoples with a wide variety of peoples throughout the world. Contact with peoples of the South Pacific and Southeast Asia, as well as with peoples from several areas of Africa and the Middle East, has shown that most of these people do not neatly fit into existing racial stereotypes. Some appear to have a mixture of Asian and African or European and African physical characteristics. Others, such as Melanesians, can easily be mistaken for African or black American. More anomalous are native Australians, some of whom have light or blond wavy hair combined with dark skins. Many Americans are recognizing that the social categories of race as evolved in the United States are inadequate for encompassing such peoples who, indeed, do not share the social history of racial minorities in the United States.

Anomalous traits

In the 1950s and '60s, Americans began experiencing an influx of new immigrants from Latin America. Spanish and Portuguese colonial societies exhibited very different attitudes toward physical differences. Even before Christopher Columbus set sail, the Mediterranean world had long been a world of heterogeneous peoples. Africans, southern Europeans, and peoples of the Middle East have interacted, and interbred over thousands of years, as long as humans have occupied these regions. The Iberian peoples brought their customs and habits to the New World. There, as described above, intermating among Europeans, Africans, and Native Americans soon began to produce a population of "mixed" peoples. The descendants of these peoples who have entered the United States since the mid-20th century further confound "racial" categories for those who believe in them.

U.S. military personnel in the Persian Gulf War (1990–91) were startled to see that many Saudi Arabians, Yemenis, Omanis, and other peoples in the Middle East resembled African Americans or Africans in their skin colour, hair texture, and facial features. Many Southeast Asians and Middle Easterners have found that they are frequently "mistaken" for blacks in America. Some American Indians are mistaken for Chinese, Japanese, or other Asian ethnic groups on the basis of their skin colour, eye structure, and hair colour and texture. Some Central and South Americans and many Puerto Ricans are perceived as Arabs. In like manner, many Arab Americans or Persians are mistaken for Latinos. "Race" is, indeed, in the eye of the beholder.

Clearly, physical features are insufficient clues to a person's ethnic identity. They reveal nothing about a person's culture, language, religion, and values. Sixth-generation Chinese Americans have American ethnicity; many know little or nothing about traditional Chinese culture, just as European Americans and African Americans may know little or nothing about the cultures of their ancestors. Moreover, all cultures change, and they do so independently of the biogenetic features of their carriers.

Physical features and identity

Modern scientific explanations of human biological variation

Contemporary scientists hold that human physical variations, especially in those traits that are normally used to classify people racially—skin colour, hair texture, facial features, and to some extent bodily structure—must be understood in terms of evolutionary processes and the long-range adaptation of human groups to differing environments. Other features may simply reflect accidental mutations or functionally neutral changes in the genetic code.

In any given habitat, natural forces operate on all of the living forms, including human groups. The necessary interaction with these forces will affect the survival and reproduction of the members of these societies. Such groups already have a wide and complex range of hereditary physical characteristics; indeed, human hereditary variability is a product of human sexual reproduction, whereby every individual receives half of his or her genetic endowment from each parent and no two individuals (except for identical twins) inherit the same combination of genetic features.

The global distribution of skin colour (see map) is the best example of adaptation, and the consequences of this process have long been well-known. Skin colour clines (gradations) in indigenous populations worldwide correlate with latitude and amounts of sunlight. Indigenous populations within a broad band known as the tropics (the regions falling in latitude between the Tropics of Cancer and Capricorn) have darker skin colours than indigenous populations outside of these regions.

Within the tropics, skin colours vary from light tan to very dark brown or black, both among populations and among individuals within groups. The darkest skin colours are found in those populations long residing in regions where intense ultraviolet sunlight is greatest and there is little natural forest cover. The bluish-black skins of some peoples—among the Dravidians of South India, among the peoples of Sri Lanka and Bangladesh, and peoples of the eastern Sudan zone, including Nubia, and the grasslands of Africa—are examples of the extremes of dark skin colour. Medium brown to dark brown peoples are found in the rest of tropical Africa and India and throughout Australia, Melanesia, and other parts of Southeast Asia.

Peoples with light skin colours evolved over thousands of years in northern temperate climates. Human groups in-

Pigmentation

termittently migrating into Europe and the northern parts of the Eurasian landmass over the past 25,000–50,000 years experienced a gradual loss of skin pigmentation. The changes were both physiological and genetic; that is, there were systemic changes in individuals and long-range genetic changes as a result of natural selection and, possibly, mutations. Those individuals with the lightest skin colours, with lowest amounts of melanin, survived and reproduced in larger numbers and thus passed on their genes for lighter skin. Over time, entire populations living in northern climates evolved lighter skin tones than those individuals living in areas with higher levels of sunlight. Between populations with light skin and those with the darkest coloration are populations with various shades of light tan to brown. The cline in skin colours shows variation by infinite degrees; any attempts to place boundaries along this cline represent purely arbitrary decisions.

Scientists at the turn of the 21st century understand how these superficial visible differences developed. Melanin, a substance that makes the skin dark, has been shown to confer protection from sunburn and skin cancers in those very areas where ultraviolet sunlight is strongest. Dark skin, which tends to be thicker than light skin, may have other protective functions in tropical environments where biting insects and other vectors of disease are constant threats to human survival. But humans also need vitamin D, which is synthesized by sunlight from sterols (chemical compounds) present in the skin. Vitamin D affects bone growth, and, without a sufficient amount, the disease known as rickets would have been devastating to early human groups trying to survive in the cold, wintry weather of the north. As these groups adapted to northern climates with limited sunlight, natural selection brought about the gradual loss of melanin in favour of skin tones that enabled some individuals to better synthesize vitamin D.

Other physical characteristics indicate adaptations to cold or hot climates, to variations in elevation from sea level, to rainforests with high levels of rainfall, and to hot deserts. Body structure and the amount of body fat have also been explained by evolutionists in terms of human adaptation to differing environments. Long, linear body build seems to be highly correlated with hot, dry climates. Such people inhabit the Sahara and the desiccated areas of the Sudan in Africa. Short, stocky body builds with stubby fingers and toes are correlated with cold, wet climates, such as are found in Arctic areas. People adapted to cold climates have acquired genetic traits that provide them extra layers of body fat, which accounts for the epicanthic fold over their eyes. People who live in areas of high elevation, as in the mountains of Peru, tend to have an adaptive feature not found among peoples who live at sea level; they have larger lungs and chest cavities. In an atmosphere where the oxygen supply is low, larger lungs are clearly adaptive.

Adaptations to cold climates

Some adaptive variations are not obviously visible or measurable. Many peoples adapted to cold climates, for example, have protective physiological reactions in their blood supply. Their blood vessels either constrict the flow to extremities to keep the inner body warm while their surface skin may be very cold (vasoconstriction) or dilate to increase the blood flow to the hands, feet, and head, to warm outer surfaces (vasodilation).

The prevalence of diseases has been another major factor in the evolution of human diversity, and some of the most important of human genetic variations reflect differences in immunities to diseases. The sickle-cell trait (hemoglobin S), for example, is found chiefly in those regions of the tropical world where malaria is endemic. Hemoglobin S in its heterozygous form (inherited from one parent only) confers some immunity to those people who carry it, although it brings a deadly disease (sickle-cell anemia) in its homozygous form (inherited from both parents).

In the last decades of the 20th century, scientists began to understand human physical variability in clinal terms and to recognize that it reflects much more complex gradations and combinations than they had anticipated. To comprehend the full expression of a feature's genetic variability, it must be studied separately over geographic space and often in terms of its adaptive value. Many features are now known to relate to the environmental conditions of the populations that carry them.

The scientific debate over "race"

Although their numbers are dwindling, some scientists continue to believe that it is possible to divide *Homo sapiens* into discrete populations called races. They believe that the physical differences manifest in wide geographic regions reflect innate intellectual, moral, emotional, and other behavioral differences among human groups. They deny that social circumstances and the cultural realities of racism have any effect on behaviour or the performance of children and adults on IQ tests. Those scientists who advocate the continued acceptance of race and racial differences have been labeled "splitters."

Splitters and lumpers

Those who deny the biological salience of race or argue against the use of the term have been labeled "lumpers." The latter see their position as being buttressed and confirmed by ongoing genetic and other research. They point out the failure of science to establish exclusive boundaries around populations or lines of rigid distinctions that the



Figure 38: The distribution of skin colour variations of indigenous populations before colonization by Europeans. The map is a reconstruction of populations based on a number of sources. It represents anthropologists' understanding at the turn of the 21st century.

Compiled by Audrey Smedley

term *race* conveys. They also point to the evidence demonstrating that all normal people regardless of their physical variations are capable of learning any kind of cultural behaviour. They argue that genes and cultural conditioning work in tandem and are inseparably fused together in the formation of individual personalities.

An increasing number of scholars and other educated people now believe that the concept of race has outlived its usefulness. However, the social realities of race and racism undoubtedly will continue as long as some individuals perceive benefits from the hierarchical structuring of social statuses based on a presumed biological identity. (A.Sm.)

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The Theory of Evolution

The diversity of the living world is staggering. More than 2 million existing species of plants and animals have been named and described; many more remain to be discovered—from 10 million to 30 million, according to some estimates. What is impressive is not just the numbers but also the incredible heterogeneity in size, shape, and way of life—from lowly bacteria, measuring less than a thousandth of a millimetre in diameter, to stately sequoias, rising 100 metres (300 feet) above the ground and weighing several thousand tons; from bacteria living in hot springs at temperatures near the boiling point of water to fungi and algae thriving on the ice masses of Antarctica and in saline pools at −23° C (−9° F); and from giant tube worms discovered living near hydrothermal vents on the dark ocean floor to spiders and larkspur plants existing on the slopes of Mount Everest more than 6,000 metres (19,700 feet) above sea level.

The virtually infinite variations on life are the fruit of the evolutionary process. All living creatures are related by descent from common ancestors. Humans and other mammals descend from shrewlike creatures that lived more than 150 million years ago; mammals, birds, reptiles, amphibians, and fishes share as ancestors aquatic worms that lived 600 million years ago; and all plants and animals derive from bacteria-like microorganisms that originated more than 3 billion years ago. Biological evolution is a process of descent with modification. Lineages of organisms change through generations; diversity arises because the lineages that descend from common ancestors diverge through time.

The 19th-century English naturalist Charles Darwin argued that organisms come about by evolution, and he provided a scientific explanation, essentially correct but incomplete, of how evolution occurs and why it is that organisms have features—such as wings, eyes, and kidneys—clearly structured to serve specific functions. Natural selection was the fundamental concept in his explanation. Natural selection occurs because individuals having more useful traits, such as more acute vision or swifter legs, survive better and produce more progeny than individuals with less favourable traits. Genetics, a science born in the 20th century, reveals in detail how natural selection works and led to the development of the modern theory of evolution. Beginning in the 1960s, a related scientific discipline, molecular biology, enormously advanced knowledge of biological evolution and made it possible to investigate detailed problems that had seemed completely out of reach only a short time previously—for example, how similar the genes of humans and chimpanzees might be (they differ in about 1–2 percent of the units that make up the genes).

This article discusses evolution as it applies generally to living things. For a discussion of human evolution, see the article EVOLUTION, HUMAN. For a more complete treatment of a discipline that has proved essential to the study of evolution, see GENETICS AND HEREDITY, THE PRINCIPLES OF. Specific aspects of evolution are discussed in the articles COLORATION, BIOLOGICAL; and MIMICRY. Applications of evolutionary theory to plant and animal breeding are discussed in the article FARMING AND AGRICULTURAL TECHNOLOGY. For an overview of the evolution of life as a major characteristic of Earth's history, see BIOSPHERE: *Evolution of the biosphere*. A detailed discussion of the life and thought of Charles Darwin is found in the article DARWIN.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 312.

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GENERAL OVERVIEW

The evidence for evolution

Darwin and other 19th-century biologists found compelling evidence for biological evolution in the comparative study of living organisms, in their geographic distribution, and in the fossil remains of extinct organisms. Since Darwin's time, the evidence from these sources has become considerably stronger and more comprehensive, while biological disciplines that have emerged more recently—genetics, biochemistry, physiology, ecology, animal behaviour (ethology), and especially molecular biology—have supplied powerful additional evidence and detailed confirmation. The amount of information about evolutionary history stored in the DNA and proteins of living things is virtually unlimited; scientists can reconstruct any detail of the evolutionary history of life by investing sufficient time and laboratory resources.

Evolutionists no longer are concerned with obtaining evidence to support the fact of evolution but rather are concerned with what sorts of knowledge can be obtained from

different sources of evidence. The following sections identify the most productive of these sources and illustrate the types of information they have provided.

THE FOSSIL RECORD

Paleontologists have recovered and studied the fossil remains of many thousands of organisms that lived in the past. This fossil record shows that many kinds of extinct organisms were very different in form from any now living. It also shows successions of organisms through time, manifesting their transition from one form to another. (See Figure 1.)

When an organism dies, it is usually destroyed by other forms of life and by weathering processes. On rare occasions some body parts—particularly hard ones such as shells, teeth, or bones—are preserved by being buried in mud or protected in some other way from predators and weather. Eventually, they may become petrified and preserved indefinitely with the rocks in which they are embedded. Methods such as radiometric dating—measuring the amounts of natural radioactive atoms that remain in certain minerals to determine the elapsed time since they were constituted—make it possible to estimate the time period when the rocks, and the fossils associated with them, were formed.

Key appearances in the fossil record

Radiometric dating indicates that Earth was formed about 4.5 billion years ago. The earliest fossils resemble microorganisms such as bacteria and cyanobacteria (blue-green algae); the oldest of these fossils appear in rocks 3.5 billion years old. The oldest known animal fossils, about 700 million years old, come from the so-called Ediacara fauna, small wormlike creatures with soft bodies. Numerous fossils belonging to many living phyla and exhibiting mineralized skeletons appear in rocks about 540 million years old. These organisms are different from organisms living now and from those living at intervening times. Some are so radically different that paleontologists have created new phyla in order to classify them. The first vertebrates, animals with backbones, appeared about 400 million years ago; the first mammals, less than 200 million years ago. The history of life recorded by fossils presents compelling evidence of evolution.

The fossil record is incomplete. Of the small proportion of organisms preserved as fossils, only a tiny fraction have been recovered and studied by paleontologists. In some cases the succession of forms over time has been reconstructed in detail. One example is the evolution of the horse, shown in Figure 2. The horse can be traced to an animal the size of a dog having several toes on each foot and teeth appropriate for browsing; this animal, called the dawn horse (genus *Hyracotherium*), lived more than 50 million years ago. The most recent form, the modern horse (*Equus*), is much larger in size, is one-toed, and has teeth appropriate for grazing. The transitional forms are well preserved as fossils, as are many other kinds of extinct horses that evolved in different directions and left no living descendants.

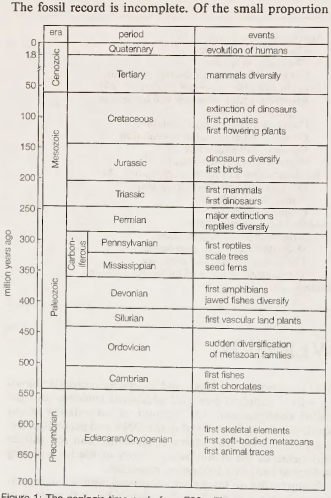


Figure 1: The geologic time scale from 700 million years ago to the present, showing major evolutionary events.

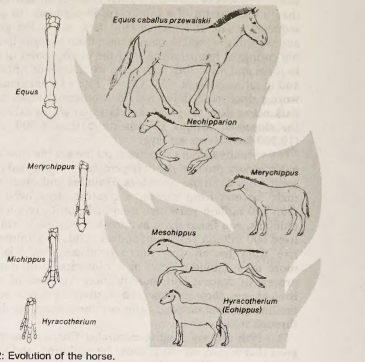


Figure 2: Evolution of the horse.
Drawing by M. Moran

Radical transitions in form and function

Using recovered fossils, paleontologists have reconstructed examples of radical evolutionary transitions in form and function. For example, the lower jaw of reptiles contains several bones, but that of mammals only one. The other bones in the reptile jaw unmistakably evolved into bones now found in the mammalian ear. At first, such a transition would seem unlikely—it is hard to imagine what function such bones could have had during their intermediate stages. Yet paleontologists discovered two transitional forms of mammal-like reptiles, called therapsids, that had a double jaw joint (*i.e.*, two hinge points side by side)—one joint consisting of the bones that persist in the mammalian jaw and the other composed of the quadrate and articular bones, which eventually became the hammer and anvil of the mammalian ear.

Finding of numerous "missing links"

For skeptical contemporaries of Darwin, the "missing link"—the absence of any known transitional form between apes and humans—was a battle cry, as it remained for uninformed people afterward. Not one but many creatures intermediate between living apes and humans have since been found as fossils. The oldest known fossil hominids—*i.e.*, primates belonging to the human lineage after it separated from lineages going to the apes—are 6 million to 7 million years old, come from Africa, and are known as *Sahelanthropus* and *Orrorin* (or *Praeanthropus*), which were predominantly bipedal when on the ground but which had very small brains. *Ardipithecus* lived about 4.4 million years ago, also in Africa. Numerous fossil remains from diverse African origins are known of *Australopithecus*, a hominid that appeared between 3 million and 4 million years ago. *Australopithecus* had an upright human stance but a cranial capacity of less than 500 cubic centimetres (equivalent to a brain weight of about 500 grams), comparable to that of a gorilla or chimpanzee and about one-third that of humans. Its head displayed a mixture of ape and human characteristics—a low forehead and a long, apelike face but with teeth proportioned like those of humans.

Other early hominids partly contemporaneous with *Australopithecus* include *Kenyanthropus* and *Paranthropus*; both had comparatively small brains, although some species of *Paranthropus* had larger bodies. *Paranthropus* represents a side branch in the hominid lineage that became extinct. Along with increased cranial capacity, other human characteristics have been found in *Homo habilis*, which lived about 1.5 million to 2 million years ago in Africa and had a cranial capacity of more than 600 cc (brain weight of 600 g), and in *H. erectus*, which lived between 500,000 and more than 1.5 million years ago, apparently ranged widely over Africa, Asia, and Europe, and had a cranial capacity of 800 to 1,100 cc (brain weight of 800 to 1,100 g). The brain sizes of *H. ergaster*, *H. antecessor*, and *H. heidelbergensis* were roughly that of the brain of *H. erectus*, some of which species were partly contemporaneous, though they lived in different regions of the Eastern Hemisphere.

STRUCTURAL SIMILARITIES

The skeletons of turtles, horses, humans, birds, and bats are strikingly similar, in spite of the different ways of life of these animals and the diversity of their environments. The correspondence, bone by bone, can easily be seen not only in the limbs (as shown in Figure 3) but also in every other part of the body. From a purely practical point of view, it is incomprehensible that a turtle should swim, a horse run, a person write, and a bird or bat fly with forelimb structures built of the same bones. An engineer could design better limbs in each case. But if it is accepted that all of these skeletons inherited their structures from a common ancestor and became modified only as they adapted to different ways of life, the similarity of their structures makes sense.

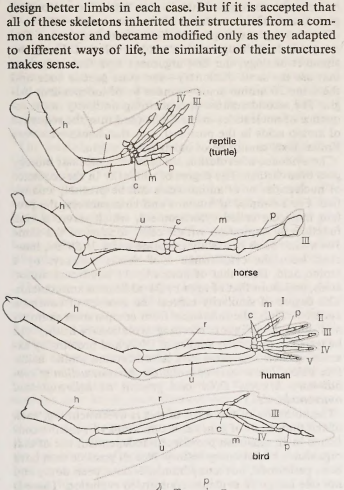


Figure 3: Homologies of the forelimb among vertebrates, giving evidence for evolution. The bones correspond, although they are adapted to the specific mode of life of the animal. The abbreviations are: h, humerus; r, radius; u, ulna; c, carpals; m, metacarpal; p, phalanx. The Roman numerals indicate corresponding digits.

Comparative anatomy investigates the homologies, or inherited similarities, among organisms in bone structure and in other parts of the body. The correspondence of structures is typically very close among some organisms—the different varieties of songbirds, for instance—but becomes less so as the organisms being compared are less closely related in their evolutionary history. The similarities are less between mammals and birds than they are among mammals, and they are still less between mammals and fishes. Similarities in structure, therefore, not only manifest evolution but also help to reconstruct the phylogeny, or evolutionary history, of organisms.

Comparative anatomy also reveals why most organismic structures are not perfect. Like the forelimbs of turtles, horses, humans, birds, and bats, an organism's body parts are less than perfectly adapted because they are modified from an inherited structure rather than designed from completely "raw" materials for a specific purpose. The imperfection of structures is evidence for evolution and against antievolutionist arguments that invoke intelligent design (see below *The cultural impact of evolutionary theory: Intelligent design and its critics*).

EMBRYONIC DEVELOPMENT AND VESTIGES

Darwin and his followers found support for evolution in the study of embryology, the science that investigates the development of organisms from fertilized egg to time of birth or hatching. Vertebrates, from fishes through lizards to humans, develop in ways that are remarkably similar during early stages, but they become more and more differentiated as the embryos approach maturity. The similarities persist longer between organisms that are more closely related (*e.g.*, humans and monkeys) than between those less closely related (humans and sharks). Common developmental patterns reflect evolutionary kinship. Lizards and humans share a developmental pattern inherited from their remote common ancestor; the inherited pattern of each was modified only as the separate descendant lineages evolved in different directions. The common embryonic stages of the two creatures reflect the constraints imposed by this common inheritance, which prevents changes that have not been necessitated by their diverging environments and ways of life.

Gill slits and tails in human embryos

The embryos of humans and other nonaquatic vertebrates exhibit gill slits even though they never breathe through gills. These slits are found in the embryos of all vertebrates because they share as common ancestors the fish in which these structures first evolved. Human embryos also exhibit by the fourth week of development a well-defined tail, which reaches maximum length at six weeks. Similar embryonic tails are found in other mammals, such as dogs, horses, and monkeys; in humans, however, the tail eventually shortens, persisting only as a rudiment in the adult coccyx.

A close evolutionary relationship between organisms that appear drastically different as adults can sometimes be recognized by their embryonic homologies. Barnacles, for example, are sedentary crustaceans with little apparent likeness to such free-swimming crustaceans as lobsters, shrimps, or copepods. Yet barnacles pass through a free-swimming larval stage, the nauplius, which is unmistakably similar to that of other crustacean larvae.

The vestigial appendix

Embryonic rudiments that never fully develop, such as the gill slits in humans, are common in all sorts of animals. Some, however, like the tail rudiment in humans, persist as adult vestiges, reflecting evolutionary ancestry. The most familiar rudimentary organ in humans is the vermiform appendix. This wormlike structure attaches to a short section of intestine called the cecum, which is located at the point where the large and small intestines join. The human vermiform appendix is a functionless vestige of a fully developed organ present in other mammals, such as the rabbit and other herbivores, where a large cecum and appendix store vegetable cellulose to enable its digestion with the help of bacteria. Vestiges are instances of imperfections—like the imperfections seen in anatomical structures—that argue against creation by design but are fully understandable as a result of evolution.

BIOGEOGRAPHY

Darwin also saw a confirmation of evolution in the geographic distribution of plants and animals, and later knowledge has reinforced his observations. For example, there are about 1,500 known species of *Drosophila* vinegar flies in the world; nearly one-third of them live in Hawaii and nowhere else, although the total area of the archipelago is less than one-twentieth the area of California or Germany. Also in Hawaii are more than 1,000 species of snails and other land mollusks that exist nowhere else. This unusual diversity is easily explained by evolution. The islands of Hawaii are extremely isolated and have had few colonizers—*i.e.,* animals and plants that arrived there from elsewhere and established populations. Those species that did colonize the islands found many unoccupied ecological niches, or local environments suited to sustaining them and lacking predators that would prevent them from multiplying. In response, these species rapidly diversified; this process of diversifying in order to fill ecological niches is called adaptive radiation.

Each of the world's continents has its own distinctive collection of animals and plants. In Africa are rhinoceroses, hippopotamuses, lions, hyenas, giraffes, zebras, lemurs, monkeys with narrow noses and nonprehensile tails, chimpanzees, and gorillas. South America, which extends over much the same latitudes as Africa, has none of these animals; it instead has pumas, jaguars, tapir, llamas, raccoons, opossums, armadillos, and monkeys with broad noses and large prehensile tails.

These vagaries of biogeography are not due solely to the suitability of the different environments. There is no reason to believe that South American animals are not well suited to living in Africa or those of Africa to living in South America. The islands of Hawaii are no better suited than other Pacific islands for vinegar flies, nor are they less hospitable than other parts of the world for many absent organisms. In fact, although no large mammals are native to the Hawaiian islands, pigs and goats have multiplied there as wild animals since being introduced by humans. This absence of many species from a hospitable environment in which an extraordinary variety of other species flourish can be explained by the theory of evolution, which holds that species can exist and evolve only in geographic areas that were colonized by their ancestors.

MOLECULAR BIOLOGY

The field of molecular biology provides the most detailed and convincing evidence available for biological evolution. In its unveiling of the nature of DNA and the workings of organisms at the level of enzymes and other protein molecules, it has shown that these molecules hold information about an organism's ancestry. This has made it possible to reconstruct evolutionary events that were previously unknown and to confirm and adjust the view of events already known. The precision with which these events can be reconstructed is one reason the evidence from molecular biology is so compelling. Another reason is that molecular evolution has shown all living organisms, from bacteria to humans, to be related by descent from common ancestors.

Molecular uniformity among organisms

A remarkable uniformity exists in the molecular components of organisms—in the nature of the components as well as in the ways in which they are assembled and used. In all bacteria, plants, animals, and humans, the DNA comprises a different sequence of the same four component nucleotides, and all of the various proteins are synthesized from different combinations and sequences of the same 20 amino acids, although several hundred other amino acids do exist. The genetic code by which the information contained in the DNA of the cell nucleus is passed on to proteins is virtually everywhere the same. Similar metabolic pathways—sequences of biochemical reactions—are used by the most diverse organisms to produce energy and to make up the cell components.

This unity reveals the genetic continuity and common ancestry of all organisms. There is no other rational way to account for their molecular uniformity when numerous alternative structures are equally likely. The genetic code serves as an example. Each particular sequence of three nucleotides in the nuclear DNA acts as a pattern for the production of exactly the same amino acid in all organisms. This is no more necessary than it is for a language to use a particular combination of letters to represent a particular object. If it is found that certain sequences of letters—*planet, tree, woman*—are used with identical meanings in a number of different books, one can be sure that the languages used in those books are of common origin.

Genes and proteins are long molecules that contain information in the sequence of their components in much the same way as sentences of the English language contain information in the sequence of their letters and words. The sequences that make up the genes are passed on from parents to offspring and are identical except for occasional changes introduced by mutations. As an illustration, one may assume that two books are being compared. Both books are 200 pages long and contain the same number of chapters. Closer examination reveals that the two books are identical page for page and word for word, except that an occasional word—say one in 100—is different. The two books cannot have been written independently; either one has been copied from the other, or both have been copied, directly or indirectly, from the same original book. Similarly, if each component nucleotide of DNA is represented by one letter, the complete sequence of nucleotides in the DNA of a higher organism would require several hundred books of hundreds of pages, with several thousand letters on each page. When the "pages" (or sequences of nucleotides) in these "books" (organisms) are examined one by one, the correspondence in the "letters" (nucleotides) gives unmistakable evidence of common origin.

The two arguments presented above are based on different grounds, although both attest to evolution. Using the alphabet analogy, the first argument says that languages that use the same dictionary—the same genetic code and the same 20 amino acids—cannot be of independent origin. The second argument, concerning similarity in the sequence of nucleotides in the DNA (and thus the sequence of amino acids in the proteins), says that books with very similar texts cannot be of independent origin.

Precise measurement of molecular similarities

The evidence of evolution revealed by molecular biology goes even farther. The degree of similarity in the sequence of nucleotides or of amino acids can be precisely quantified. For example, in humans and chimpanzees, the protein molecule called cytochrome c, which serves a vital function in respiration within cells, consists of the same 104 amino acids in exactly the same order. It differs, however, from the cytochrome c of rhesus monkeys by 1 amino acid, from that of horses by 11 additional amino acids, and from that of tuna by 21 additional amino acids. The degree of similarity reflects the recency of common ancestry. Thus, the inferences from comparative anatomy and other disciplines concerning evolutionary history can be tested in molecular studies of DNA and proteins by examining their sequences of nucleotides and amino acids. (See below *The science of evolution: Reconstruction of evolutionary history: DNA and protein as informational macromolecules*.)

The authority of this kind of test is overwhelming; each of the thousands of genes and thousands of proteins contained in an organism provides an independent test of that organism's evolutionary history. Not all possible tests have been performed, but many hundreds have been done, and not one has given evidence contrary to evolution. There is probably no other notion in any field of science that has been as extensively tested and as thoroughly corroborated as the evolutionary origin of living organisms.

History of evolutionary theory

EARLY IDEAS

All human cultures have developed their own explanations for the origin of the world and of human beings and other creatures. Traditional Judaism and Christianity explain the origin of living beings and their adaptations to their environments—wings, gills, hands, flowers—as the handiwork of an omniscient God. The philosophers of ancient Greece had their own creation myths. Anaximander proposed that animals could be transformed from one kind into another, and Empedocles speculated that they were made up of var-

Thinking of early Church Fathers

ious combinations of preexisting parts. Closer to modern evolutionary ideas were the proposals of early Church Fathers such as Gregory of Nazianzus and Augustine, both of whom maintained that not all species of plants and animals were created by God; rather, some had developed in historical times from God's creations. Their motivation was not biological but religious—it would have been impossible to hold representatives of all species in a single vessel such as Noah's Ark; hence, some species must have come into existence only after the Flood.

The notion that organisms may change by natural processes was not investigated as a biological subject by Christian theologians of the Middle Ages, but it was, usually incidentally, considered as a possibility by many, including Albertus Magnus and his student Thomas Aquinas. Aquinas concluded, after detailed discussion, that the development of living creatures such as maggots and flies from nonliving matter such as decaying meat was not incompatible with Christian faith or philosophy. But he left it to others to determine whether this actually happened.

The idea of progress, particularly the belief in unbounded human progress, was central to the Enlightenment of the 18th century, particularly in France among such philosophers as the marquis de Condorcet and Denis Diderot and such scientists as Georges-Louis Leclerc, comte de Buffon. But belief in progress did not necessarily lead to the development of a theory of evolution. Pierre-Louis Moreau de Maupertuis proposed the spontaneous generation and extinction of organisms as part of his theory of origins, but he advanced no theory of evolution—*i.e.*, the transformation of one species into another through knowable, natural causes. Buffon, one of the greatest naturalists of the time, explicitly considered—and rejected—the possible descent of several species from a common ancestor. He postulated that organisms arise from organic molecules by spontaneous generation, so that there could be as many kinds of animals and plants as there are viable combinations of organic molecules.

The English physician Erasmus Darwin, grandfather of Charles Darwin, offered in his *Zoonomia; or, The Laws of Organic Life* (1794–96) some evolutionary speculations, but they were not further developed and had no real influence on subsequent theories. The Swedish botanist Carolus Linnaeus devised the hierarchical system of plant and animal classification that is still in use in a modernized form. Although he insisted on the fixity of species, his classification system eventually contributed much to the acceptance of the concept of common descent.

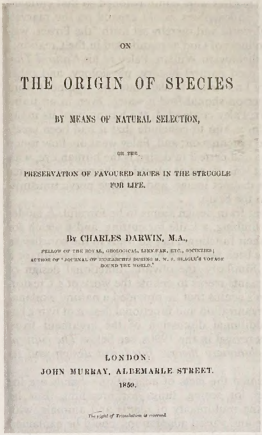
Lamarck's theory of evolution

The great French naturalist Jean-Baptiste Lamarck held the enlightened view of his age that living organisms represent a progression, with humans as the highest form. From this idea he proposed, in the early years of the 19th century, the first broad theory of evolution. Organisms evolve through eons of time from lower to higher forms, a process still going on, always culminating in human beings. As organisms become adapted to their environments through their habits, modifications occur. Use of an organ or structure reinforces it; disuse leads to obliteration. The characteristics acquired by use and disuse, according to this theory, would be inherited. This assumption, later called the inheritance of acquired characteristics (or Lamarckism), was thoroughly disproved in the 20th century. Although his theory did not stand up in the light of later knowledge, Lamarck made important contributions to the gradual acceptance of biological evolution and stimulated countless later studies.

CHARLES DARWIN

The founder of the modern theory of evolution was Charles Darwin. The son and grandson of physicians, he enrolled as a medical student at the University of Edinburgh. After two years he left to study at the University of Cambridge and prepare to become a clergyman. He was not an exceptional student, but he was deeply interested in natural history. On Dec. 27, 1831, a few months after his graduation from Cambridge, he sailed as a naturalist aboard the HMS *Beagle* on a round-the-world trip that lasted until October 1836. Darwin was often able to disembark for extended trips ashore to collect natural specimens.

The discovery of fossil bones from large extinct mammals in Argentina and the observation of numerous species of finches in the Galapagos Islands were among the events credited with stimulating Darwin's interest in how species originate. In 1859 he published *On the Origin of Species by Means of Natural Selection*, a treatise establishing the theory of evolution and, most important, the role of natural selection in determining its course. He published many other books as well, notably *The Descent of Man and Selection in Relation to Sex* (1871), which extends the theory of natural selection to human evolution.



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

By CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL SOCIETIES; AUTHOR OF "JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD."

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

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Figure 4: Title page of the 1859 edition of Charles Darwin's *On the Origin of Species by Means of Natural Selection*.
Library of Congress, Washington, D.C.

Darwin must be seen as a great intellectual revolutionary who inaugurated a new era in the cultural history of humankind—the second and final stage of the Copernican revolution begun in the 16th and 17th centuries by men such as Nicolaus Copernicus, Galileo, and Isaac Newton. The Copernican revolution marked the beginnings of modern science. Discoveries in astronomy and physics overturned traditional conceptions of the universe. Earth was seen no longer as the centre of the universe but as a small planet revolving around one of myriad stars; the seasons and the rains that make crops grow, as well as destructive storms and other vagaries of weather, became understood as aspects of natural processes; the revolutions of the planets were now explained by simple laws that also accounted for the motion of projectiles on Earth.

The universe as accessible to science

The significance of these and other discoveries was that they led to a conception of the universe as a system of matter in motion governed by laws of nature. The workings of the universe no longer needed to be attributed to the ineffable will of a divine Creator; rather, they were brought into the realm of science—an explanation of phenomena through natural laws. Physical phenomena such as tides, eclipses, and positions of the planets could now be predicted whenever the causes were adequately known. Darwin accumulated evidence showing that evolution had occurred, that diverse organisms share common ancestors, and that living beings have changed drastically over the course of Earth's history. More important, however, he extended to the living world the idea of nature as a system of matter in motion governed by natural laws.

Before Darwin, the origin of Earth's living things, with their marvelous contrivances for adaptation, had been at-

tributed to the design of an omniscient God. He had created the fish in the waters, the birds in the air, and all sorts of animals and plants on the land. God had endowed these creatures with gills for breathing, wings for flying, and eyes for seeing, and he had coloured birds and flowers so that human beings could enjoy them and recognize God's wisdom. Christian theologians, from Aquinas on, had argued that the presence of design, so evident in living beings, demonstrates the existence of a supreme Creator; the argument from design was Aquinas's "fifth way" for proving the existence of God. In 19th-century England the eight Bridgewater Treatises were commissioned so that eminent scientists and philosophers would expand on the marvels of the natural world and thereby set forth "the Power, wisdom, and goodness of God as manifested in the Creation."

Paley's argument from design

The British theologian William Paley in his *Natural Theology* (1802) used natural history, physiology, and other contemporary knowledge to elaborate the argument from design. If a person should find a watch, even in an uninhabited desert, Paley contended, the harmony of its many parts would force him to conclude that it had been created by a skilled watchmaker; and, Paley went on, how much more intricate and perfect in design is the human eye, with its transparent lens, its retina placed at the precise distance for forming a distinct image, and its large nerve transmitting signals to the brain.

The argument from design seems to be forceful. A ladder is made for climbing, a knife for cutting, and a watch for telling time; their functional design leads to the conclusion that they have been fashioned by a carpenter, a smith, or a watchmaker. Similarly, the obvious functional design of animals and plants seems to denote the work of a Creator. It was Darwin's genius that he provided a natural explanation for the organization and functional design of living beings. (For additional discussion of the argument from design and its revival in the 1990s, see below *The cultural impact of evolutionary theory: Intelligent design and its critics*.)

Darwin accepted the facts of adaptation—hands are for grasping, eyes for seeing, lungs for breathing. But he showed that the multiplicity of plants and animals, with their exquisite and varied adaptations, could be explained by a process of natural selection, without recourse to a Creator or any designer agent. This achievement would prove to have intellectual and cultural implications more profound and lasting than his multipronged evidence that convinced contemporaries of the fact of evolution.

Darwin's theory of natural selection

Darwin's theory of natural selection is summarized in the *Origin of Species* as follows:

> As many more individuals are produced than can possibly survive, there must in every case be a struggle for existence, either one individual with another of the same species, or with the individuals of distinct species, or with the physical conditions of life.... Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life, should sometimes occur in the course of thousands of generations? If such do occur, can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and of procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favourable variations and the rejection of injurious variations, I call Natural Selection.

Natural selection was proposed by Darwin primarily to account for the adaptive organization of living beings; it is a process that promotes or maintains adaptation. Evolutionary change through time and evolutionary diversification (multiplication of species) are not directly promoted by natural selection, but they often ensue as by-products of natural selection as it fosters adaptation to different environments.

MODERN CONCEPTIONS

The Darwinian aftermath. The publication of the *Origin of Species* produced considerable public excitement. Scientists, politicians, clergymen, and notables of all kinds read and discussed the book, defending or deriding Darwin's ideas. The most visible actor in the controversies immediately following publication was the English biologist T.H. Huxley, known as "Darwin's bulldog," who defended the theory of evolution with articulate and sometimes mordant words on public occasions as well as in numerous writings. Evolution by natural selection was indeed a favourite topic in society salons during the 1860s and beyond. But serious scientific controversies also arose, first in Britain and then on the Continent and in the United States.

Wallace's concept of natural selection

One occasional participant in the discussion was the British naturalist Alfred Russel Wallace, who had hit upon the idea of natural selection independently and had sent a short manuscript about it to Darwin from the Malay Archipelago, where he was collecting specimens and writing. On July 1, 1858, one year before the publication of the *Origin*, a paper jointly authored by Wallace and Darwin was presented, in the absence of both, to the Linnean Society in London—with apparently little notice. Greater credit is duly given to Darwin than to Wallace for the idea of evolution by natural selection; Darwin developed the theory in considerably more detail, provided far more evidence for it, and was primarily responsible for its acceptance. Wallace's views differed from Darwin's in several ways, most importantly in that Wallace did not think natural selection sufficient to account for the origin of human beings, which in his view required direct divine intervention.

A younger English contemporary of Darwin, with considerable influence during the latter part of the 19th and early 20th centuries, was Herbert Spencer. A philosopher rather than a biologist, he became an energetic proponent of evolutionary ideas, popularized a number of slogans, such as "survival of the fittest" (which was taken up by Darwin in later editions of the *Origin*), and engaged in social and metaphysical speculations. His ideas considerably damaged proper understanding and acceptance of the theory of evolution by natural selection. Darwin wrote of Spencer's speculations:

> His deductive manner of treating any subject is wholly opposed to my frame of mind.... His fundamental generalizations (which have been compared in importance by some persons with Newton's laws) which I dare say may be very valuable under a philosophical point of view, are of such a nature that they do not seem to me to be of any strictly scientific use.

Most pernicious was the crude extension by Spencer and others of the notion of the "struggle for existence" to human economic and social life that became known as social Darwinism (see below *The cultural impact of evolutionary theory: Scientific acceptance and extension to other disciplines*).

The most serious difficulty facing Darwin's evolutionary theory was the lack of an adequate theory of inheritance that would account for the preservation through the generations of the variations on which natural selection was supposed to act. Contemporary theories of "blending inheritance" proposed that offspring merely struck an average between the characteristics of their parents. But as Darwin became aware, blending inheritance (including his own theory of "pangenesis," in which each organ and tissue of an organism throws off tiny contributions of itself that are collected in the sex organs and determine the configuration of the offspring) could not account for the conservation of variations, because differences between variant offspring would be halved each generation, rapidly reducing the original variation to the average of the preexisting characteristics.

The missing link in Darwin's argument was provided by Mendelian genetics. About the time the *Origin of Species* was published, the Augustinian monk Gregor Mendel was starting a long series of experiments with peas in the garden of his monastery in Brünn, Austria-Hungary (now Brno, Czech Republic). These experiments and the analysis of their results are by any standard an example of masterly scientific method. Mendel's paper, published in 1866 in the *Proceedings* of the Natural Science Society of Brünn, formulated the fundamental principles of the theory of heredity. His theory accounts for biological inheritance through particulate factors (now known as genes) inherited one from each parent, which do not mix or blend but segregate in the formation of the sex cells, or gametes.

Mendel's principles of heredity

Mendel's discoveries, however, remained unknown to

Darwin and, indeed, did not become generally known until 1900, when they were simultaneously rediscovered by a number of scientists on the Continent. In the meantime, Darwinism, in the latter part of the 19th century, faced an alternative evolutionary theory known as neo-Lamarckism. This hypothesis shared with Lamarck's the importance of use and disuse in the development and obliteration of organs, and it added the notion that the environment acts directly on organic structures, which explained their adaptation to the way of life and environment of the organism. Adherents of this theory discarded natural selection as an explanation for adaptation to the environment.

Prominent among the defenders of natural selection was the German biologist August Weismann, who in the 1880s published his germ-plasm theory. He distinguished two substances that make up an organism: the soma, which comprises most body parts and organs, and the germ plasm, which contains the cells that give rise to the gametes and hence to progeny. Early in the development of an egg, the germ plasm becomes segregated from the somatic cells that give rise to the rest of the body. This notion of a radical separation between germ plasm and soma—that is, between the reproductive tissues and all other body tissues—prompted Weismann to assert that inheritance of acquired characteristics was impossible, and it opened the way for his championship of natural selection as the only major process that would account for biological evolution. Weismann's ideas became known after 1896 as neo-Darwinism.

The synthetic theory. The rediscovery in 1900 of Mendel's theory of heredity, by the Dutch botanist and geneticist Hugo de Vries and others, led to an emphasis on the role of heredity in evolution. De Vries proposed a new theory of evolution known as mutationism, which essentially did away with natural selection as a major evolutionary process. According to de Vries (who was joined by other geneticists such as William Bateson in England), two kinds of variation take place in organisms. One is the "ordinary" variability observed among individuals of a species, which is of no lasting consequence in evolution because, according to de Vries, it could not "lead to a transgression of the species border [*i.e.*, to establishment of new species] even under conditions of the most stringent and continued selection." The other consists of the changes brought about by mutations, spontaneous alterations of genes that result in large modifications of the organism and give rise to new species: "The new species thus originates suddenly, it is produced by the existing one without any visible preparation and without transition."

Mutationism was opposed by many naturalists and in particular by the so-called biometricians, led by the English statistician Karl Pearson, who defended Darwinian natural selection as the major cause of evolution through the cumulative effects of small, continuous, individual variations (which the biometricians assumed passed from one generation to the next without being limited by Mendel's laws of inheritance).

The controversy between mutationists (also referred to at the time as Mendelians) and biometricians approached a resolution in the 1920s and '30s through the theoretical work of geneticists. These scientists used mathematical arguments to show, first, that continuous variation (in such characteristics as body size, number of eggs laid, and the like) could be explained by Mendel's laws, and, second, that natural selection acting cumulatively on small variations could yield major evolutionary changes in form and function. Distinguished members of this group of theoretical geneticists were R.A. Fisher and J.B.S. Haldane in Britain and Sewall Wright in the United States. Their work contributed to the downfall of mutationism and, most important, provided a theoretical framework for the integration of genetics into Darwin's theory of natural selection. Yet their work had a limited impact on contemporary biologists for several reasons—it was formulated in a mathematical language that most biologists could not understand; it was almost exclusively theoretical, with little empirical corroboration; and it was limited in scope, largely omitting many issues, such as speciation (the process by which new species are formed), that were of great importance to evolutionists.

Mathematical integration of genetics and natural selection

A major breakthrough came in 1937 with the publication of *Genetics and the Origin of Species* by Theodosius Dobzhansky, a Russian-born American naturalist and experimental geneticist. Dobzhansky's book advanced a reasonably comprehensive account of the evolutionary process in genetic terms, laced with experimental evidence supporting the theoretical argument. *Genetics and the Origin of Species* may be considered the most important landmark in the formulation of what came to be known as the synthetic theory of evolution, effectively combining Darwinian natural selection and Mendelian genetics. It had an enormous impact on naturalists and experimental biologists, who rapidly embraced the new understanding of the evolutionary process as one of genetic change in populations. Interest in evolutionary studies was greatly stimulated, and contributions to the theory soon began to follow, extending the synthesis of genetics and natural selection to a variety of biological fields.

Dobzhansky's landmark achievement

The main writers who, together with Dobzhansky, may be considered the architects of the synthetic theory were the German-born American zoologist Ernst Mayr, the English zoologist Julian Huxley, the American paleontologist George Gaylord Simpson, and the American botanist George Ledyard Stebbins. These researchers contributed to a burst of evolutionary studies in the traditional biological disciplines and in some emerging ones—notably population genetics and, later, evolutionary ecology. By 1950 acceptance of Darwin's theory of evolution by natural selection was universal among biologists, and the synthetic theory had become widely adopted.

Molecular biology and Earth sciences. The most important line of investigation after 1950 was the application of molecular biology to evolutionary studies. In 1953 the American geneticist James Watson and the British biophysicist Francis Crick deduced the molecular structure of DNA (deoxyribonucleic acid), the hereditary material contained in the chromosomes of every cell's nucleus. The genetic information is encoded within the sequence of nucleotides that make up the chainlike DNA molecules. This information determines the sequence of amino-acid building blocks of protein molecules, which include, among others, structural proteins such as collagen, respiratory proteins such as hemoglobin, and numerous enzymes responsible for the organism's fundamental life processes. Genetic information contained in the DNA can thus be investigated by examining the sequences of amino acids in the proteins.

In the mid-1960s laboratory techniques such as electrophoresis and selective assay of enzymes became available for the rapid and inexpensive study of differences among enzymes and other proteins. The application of these techniques to evolutionary problems made possible the pursuit of issues that earlier could not be investigated—for example, exploring the extent of genetic variation in natural populations (which sets bounds on their evolutionary potential) and determining the amount of genetic change that occurs during the formation of new species.

Comparisons of the amino-acid sequences of corresponding proteins in different species provided quantitatively precise measures of the divergence among species evolved from common ancestors, a considerable improvement over the typically qualitative evaluations obtained by comparative anatomy and other evolutionary subdisciplines. In 1968 the Japanese geneticist Motoo Kimura proposed the neutrality theory of molecular evolution, which assumes that, at the level of the sequences of nucleotides in DNA and of amino acids in proteins, many changes are adaptively neutral—they have little or no effect on the molecule's function and thus on an organism's fitness within its environment. If the neutrality theory is correct, there should be a "molecular clock" of evolution; that is, the degree to which amino-acid or nucleotide sequences diverge between species should provide a reliable estimate of the time since the species diverged. This would make it possible to reconstruct an evolutionary history that would reveal the order of branching of different lineages, such as those leading to humans, chimpanzees, and orangutans, as well as the time in the past when the lineages split from one another. During the 1970s and '80s it gradually became

Neutrality theory and the "molecular clock"

clear that the molecular clock is not exact; nevertheless, into the early 21st century it continued to provide the most reliable evidence for reconstructing evolutionary history. (See below *The science of evolution: Molecular evolution. The molecular clock of evolution* and *The neutrality theory of molecular evolution*.)

The laboratory techniques of DNA cloning and sequencing have provided a new and powerful means of investigating evolution at the molecular level. The fruits of this technology began to accumulate during the 1980s following the development of automated DNA-sequencing machines and the invention of the polymerase chain reaction (PCR), a simple and inexpensive technique that obtains, in a few hours, billions or trillions of copies of a specific DNA sequence or gene. Major research efforts such as the Human Genome Project further improved the technology for obtaining long DNA sequences rapidly and inexpensively. By the first few years of the 21st century, the full DNA sequence—*i.e.*, the full genetic complement, or genome—had been obtained for more than 20 higher organisms, including human beings, the house mouse (*Mus musculus*), the rat *Rattus norvegicus*, the vinegar fly *Drosophila melanogaster*, the mosquito *Anopheles gambiae*, the nematode worm *Caenorhabditis elegans*, the malaria parasite *Plasmodium falciparum*, the mustard weed *Arabidopsis thaliana*, and the yeast *Saccharomyces cerevisiae*, as well as for numerous microorganisms.

Genome sequencing efforts

The Earth sciences also experienced, in the second half of the 20th century, a conceptual revolution with considerable consequence to the study of evolution. The theory of plate tectonics, which was formulated in the late 1960s, revealed that the configuration and position of the continents and oceans are dynamic, rather than static, features of Earth. Oceans grow and shrink, while continents break into fragments or coalesce into larger masses. The continents move across Earth's surface at rates of a few centimetres a year, and over millions of years of geologic history this movement profoundly alters the face of the planet, causing major climatic changes along the way. These previously unsuspected massive modifications of Earth's past environments, of necessity, are reflected in the evolutionary history of life. Biogeography, the evolutionary study of plant and animal distribution, has been revolutionized by the knowledge, for example, that Africa and South America were part of a single landmass some 200 million years ago and that the Indian subcontinent was not connected with Asia until geologically recent times.

Ecology, the study of the interactions of organisms with their environments, has evolved from descriptive studies—"natural history"—into a vigorous biological discipline with a strong mathematical component, both in the development of theoretical models and in the collection and analysis of quantitative data. Evolutionary ecology is an active field of evolutionary biology; another is evolutionary ethology, the study of the evolution of animal behaviour. Sociobiology, the evolutionary study of social behaviour, is perhaps the most active subfield of ethology. It is also the most controversial because of its extension to human societies.

The cultural impact of evolutionary theory

SCIENTIFIC ACCEPTANCE AND EXTENSION TO OTHER DISCIPLINES

The theory of evolution makes statements about three different, though related, issues: (1) the fact of evolution—that is, that organisms are related by common descent; (2) evolutionary history—the details of when lineages split from one another and of the changes that occurred in each lineage; and (3) the mechanisms or processes by which evolutionary change occurs.

The first issue is the most fundamental and the one established with utmost certainty. Darwin gathered much evidence in its support, but evidence has accumulated continuously ever since, derived from all biological disciplines. The evolutionary origin of organisms is today a scientific conclusion established with the kind of certainty attributable to such scientific concepts as the roundness of Earth, the motions of the planets, and the molecular composition of matter. This degree of certainty beyond reasonable doubt is what is implied when biologists say that evolution is a "fact"; the evolutionary origin of organisms is accepted by virtually every biologist.

Scientific certainty of evolution

But the theory of evolution goes far beyond the general affirmation that organisms evolve. The second and third issues—seeking to ascertain evolutionary relationships between particular organisms and the events of evolutionary history, as well as to explain how and why evolution takes place—are matters of active scientific investigation. Some conclusions are well established. One, for example, is that the chimpanzee and the gorilla are more closely related to humans than is any of those three species to the baboon or other monkeys. Another conclusion is that natural selection, the process postulated by Darwin, explains the configuration of such adaptive features as the human eye and the wings of birds. Many matters are less certain, others are conjectural, and still others—such as the characteristics of the first living things and when they came about—remain completely unknown.

Since Darwin, the theory of evolution has gradually extended its influence to other biological disciplines, from physiology to ecology and from biochemistry to systematics. All biological knowledge now includes the phenomenon of evolution. In the words of Theodosius Dobzhansky, "Nothing in biology makes sense except in the light of evolution."

The term *evolution* and the general concept of change through time also have penetrated into scientific language well beyond biology, and even into common language. Astrophysicists speak of the evolution of the solar system or of the universe; geologists, of the evolution of Earth's interior; psychologists, of the evolution of the mind; anthropologists, of the evolution of cultures; art historians, of the evolution of architectural styles; and couturiers, of the evolution of fashion. These and other disciplines use the word with only the slightest commonality of meaning—the notion of gradual, and perhaps directional, change over the course of time.

Toward the end of the 20th century, specific concepts and processes borrowed from biological evolution and living systems were incorporated into computational research, beginning with the work of the American mathematician John Holland and others. One outcome of this endeavour was the development of methods for automatically generating computer-based systems that are proficient at given tasks. These systems have a wide variety of potential uses, such as solving practical computational problems, providing machines with the ability to learn from experience, and modeling processes in fields as diverse as ecology, immunology, economics, and even biological evolution itself.

"Evolving" computer programs

To generate computer programs that represent proficient solutions to a problem under study, the computer scientist creates a set of step-by-step procedures, called a genetic algorithm or, more broadly, an evolutionary algorithm, that incorporates analogies of genetic processes—for instance, heredity, mutation, and recombination—as well as of evolutionary processes such as natural selection in the presence of specified environments. The algorithm is designed typically to simulate the biological evolution of a population of individual computer programs through successive generations to improve their "fitness" for carrying out a designated task. Each program in an initial population receives a fitness score that measures how well it performs in a specific "environment"—for example, how efficiently it sorts a list of numbers or allocates the floor space in a new factory design. Only those with the highest scores are selected to "reproduce"—to contribute "hereditary" material, *i.e.*, computer code, to the following generation of programs. The rules of reproduction may involve such elements as recombination (strings of code from the best programs are shuffled and combined into the programs of the next generation) and mutation (bits of code in a few of the new programs are changed at random). The evolutionary algorithm then evaluates each program in the new generation for fitness, winnows out the poorer performers, and allows reproduction to take place once again, with the cycle repeating itself as often as desired. Evolutionary algorithms are simplistic compared with biological evolu-

tion, but they have provided robust and powerful mechanisms for finding solutions to all sorts of problems in economics, industrial production, and the distribution of goods and services.

Influence on socio-political theory and economics

Darwin's notion of natural selection also has been extended to areas of human discourse outside the scientific setting, particularly in the fields of sociopolitical theory and economics. The extension can be only metaphoric, because in Darwin's intended meaning natural selection applies only to hereditary variations in entities endowed with biological reproduction—that is, to living organisms. That natural selection is a natural process in the living world has been taken by some as a justification for ruthless competition and for "survival of the fittest" in the struggle for economic advantage or for political hegemony. Social Darwinism was an influential social philosophy in some circles through the late 19th and early 20th centuries, when it was used as a rationalization for racism, colonialism, and social stratification. At the other end of the political spectrum, Marxist theorists have resorted to evolution by natural selection as an explanation for humankind's political history.

Darwinism understood as a process that favours the strong and successful and eliminates the weak and failing has been used to justify alternative and, in some respects, quite diametric economic theories. These theories share in common the premise that the valuation of all market products depends on a Darwinian process. Specific market commodities are evaluated in terms of the degree to which they conform to specific valuations emanating from the consumers. On the one hand, some of these economic theories are consistent with theories of evolutionary psychology that see preferences as determined largely genetically; as such, they hold that the reactions of markets can be predicted in terms of largely fixed human attributes. The dominant neo-Keynesian and monetarist schools of economics make predictions of the macroscopic behaviour of economies based on the interrelationship of a few variables—money supply, rate of inflation, and rate of unemployment jointly determine the rate of economic growth. On the other hand, some minority economists, such as the 20th-century Austrian-born British theorist Friedrich von Hayek and his followers, predicate the Darwinian process on individual preferences that are mostly underdetermined and change in erratic or unpredictable ways. According to them, old ways of producing goods and services are continuously replaced by new inventions and behaviours. These theorists affirm that what drives the economy is the ingenuity of individuals and corporations and their ability to bring new and better products to the market.

RELIGIOUS CRITICISM AND ACCEPTANCE

The theory of evolution has been seen by some people as incompatible with religious beliefs, particularly those of Christianity. The first chapters of the biblical book of Genesis describe God's creation of the world, the plants, the animals, and human beings. A literal interpretation of Genesis seems incompatible with the gradual evolution of humans and other organisms by natural processes. Independently of the biblical narrative, the Christian beliefs in the immortality of the soul and in humans as "created in the image of God" have appeared to many as contrary to the evolutionary origin of humans from nonhuman animals.

Equation of evolutionary theory with atheism

Religiously motivated attacks started during Darwin's lifetime. In 1874 Charles Hodge, an American Protestant theologian, published *What Is Darwinism?*, one of the most articulate assaults on evolutionary theory. Hodge perceived Darwin's theory as "the most thoroughly naturalistic that can be imagined and far more atheistic than that of his predecessor Lamarck." He argued that the design of the human eye evinces that "it has been planned by the Creator, like the design of a watch evinces a watchmaker." He concluded that "the denial of design in nature is actually the denial of God."

Other Protestant theologians saw a solution to the difficulty through the argument that God operates through intermediate causes. The origin and motion of the planets could be explained by the law of gravity and other natural processes without denying God's creation and providence. Similarly, evolution could be seen as the natural process through which God brought living beings into existence and developed them according to his plan. Thus, A.H. Strong, the president of Rochester Theological Seminary in New York state, wrote in his *Systematic Theology* (1885): "We grant the principle of evolution, but we regard it as only the method of divine intelligence." The brutish ancestry of human beings was not incompatible with their excelling status as creatures in the image of God. Strong drew an analogy with Christ's miraculous conversion of water into wine: "The wine in the miracle was not water because water had been used in the making of it, nor is man a brute because the brute has made some contributions to its creation." Arguments for and against Darwin's theory came from Roman Catholic theologians as well.

Acceptance by mainstream Christianity

Gradually, well into the 20th century, evolution by natural selection came to be accepted by the majority of Christian writers. Pope Pius XII in his encyclical *Humani generis* (1950; "Of the Human Race") acknowledged that biological evolution was compatible with the Christian faith, although he argued that God's intervention was necessary for the creation of the human soul. Pope John Paul II, in an address to the Pontifical Academy of Sciences on Oct. 22, 1996, deplored interpreting biblical texts as scientific statements rather than religious teachings, adding:

> New scientific knowledge has led us to realize that the theory of evolution is no longer a mere hypothesis. It is indeed remarkable that this theory has been progressively accepted by researchers, following a series of discoveries in various fields of knowledge. The convergence, neither sought nor fabricated, of the results of work that was conducted independently is in itself a significant argument in favor of this theory.

Similar views were expressed by other mainstream Christian denominations. The General Assembly of the United Presbyterian Church in 1982 adopted a resolution stating that "Biblical scholars and theological schools...find that the scientific theory of evolution does not conflict with their interpretation of the origins of life found in Biblical literature." The Lutheran World Federation in 1965 affirmed that "evolution's assumptions are as much around us as the air we breathe and no more escapable. At the same time theology's affirmations are being made as responsibly as ever. In this sense both science and religion are here to stay, and...need to remain in a healthful tension of respect toward one another." Similar statements have been advanced by Jewish authorities and those of other major religions. In 1984 the 95th Annual Convention of the Central Conference of American Rabbis adopted a resolution stating:

> Whereas the principles and concepts of biological evolution are basic to understanding science...we call upon science teachers and local school authorities in all states to demand quality textbooks that are based on modern, scientific knowledge and that exclude "scientific" creationism.

Opposing these views were Christian denominations that continued to hold a literal interpretation of the Bible. A succinct expression of this interpretation is found in the Statement of Belief of the Creation Research Society, founded in 1963 as a "professional organization of trained scientists and interested laypersons who are firmly committed to scientific special creation":

> The Bible is the Written Word of God, and because it is inspired throughout, all of its assertions are historically and scientifically true in the original autographs. To the student of nature this means that the account of origins in Genesis is a factual presentation of simple historical truths.

Differing creation accounts in Genesis

Many Bible scholars and theologians have long rejected a literal interpretation as untenable, however, because the Bible contains incompatible statements. The very beginning of the book of Genesis presents two different creation narratives. Extending through chapter 1 and the first verses of chapter 2 is the familiar six-day narrative, in which God creates human beings—both "male and female"—in his own image on the sixth day, after creating light, Earth, firmament, fish, fowl, and cattle. But in verse 4 of chapter 2 a different narrative starts, in which God creates a male human, then plants a garden and creates the animals, and only then proceeds to take a rib from the man to make a woman.

Biblical scholars point out that the Bible is inerrant with respect to religious truth, not in matters of no significance to salvation. Augustine, considered by many the greatest Christian theologian, wrote in the early 5th century in his *De Genesi ad litteram* (*Literal Commentary on Genesis*):

> It is also frequently asked what our belief must be about the form and shape of heaven, according to Sacred Scripture. Many scholars engage in lengthy discussions on these matters, but the sacred writers with their deeper wisdom have omitted them. Such subjects are of no profit for those who seek beatitude. And what is worse, they take up very precious time that ought to be given to what is spiritually beneficial. What concern is it of mine whether heaven is like a sphere and Earth is enclosed by it and suspended in the middle of the universe, or whether heaven is like a disk and the Earth is above it and hovering to one side.

Augustine adds later in the same chapter: "In the matter of the shape of heaven, the sacred writers did not wish to teach men facts that could be of no avail for their salvation." Augustine is saying that the book of Genesis is not an elementary book of astronomy. It is a book about religion, and it is not the purpose of its religious authors to settle questions about the shape of the universe that are of no relevance whatsoever to how to seek salvation.

In the same vein, John Paul II said in 1981:

> The Bible itself speaks to us of the origin of the universe and its make-up, not in order to provide us with a scientific treatise but in order to state the correct relationships of man with God and with the universe. Sacred scripture wishes simply to declare that the world was created by God, and in order to teach this truth it expresses itself in the terms of the cosmology in use at the time of the writer....Any other teaching about the origin and make-up of the universe is alien to the intentions of the Bible, which does not wish to teach how the heavens were made but how one goes to heaven.

John Paul's argument was clearly a response to Christian fundamentalists who see in Genesis a literal description of how the world was created by God. In modern times biblical fundamentalists have made up a minority of Christians, but they have periodically gained considerable public and political influence, particularly in the United States. Opposition to the teaching of evolution in the United States can largely be traced to two movements with 19th-century roots, Seventh-day Adventism and Pentecostalism. Consistent with their emphasis on the seventh-day Sabbath as a memorial of the biblical Creation, Seventh-day Adventists have insisted on the recent creation of life and the universality of the Flood, which they believe deposited the fossil-bearing rocks. This distinctively Adventist interpretation of Genesis became the hard core of "creation science" in the late 20th century and was incorporated into the "balanced-treatment" laws of Arkansas and Louisiana (discussed below). Many Pentecostals, who generally endorse a literal interpretation of the Bible, also have adopted and endorsed the tenets of creation science, including the recent origin of Earth and a geology interpreted in terms of the Flood. They have differed from Seventh-day Adventists and other adherents of creation science, however, in their tolerance of diverse views and the limited import they attribute to the evolution-creation controversy.

Biblical fundamentalism and creation science

During the 1920s, biblical fundamentalists helped influence more than 20 state legislatures to debate antievolution laws, and four states—Arkansas, Mississippi, Oklahoma, and Tennessee—prohibited the teaching of evolution in their public schools. A spokesman for the antievolutionists was William Jennings Bryan, three times the unsuccessful Democratic candidate for the U.S. presidency, who said in 1922, "We will drive Darwinism from our schools." In 1925 Bryan took part in the prosecution of John T. Scopes, a high-school teacher in Dayton, Tennessee, who had admittedly violated the state's law forbidding the teaching of evolution.

Scopes trial

In 1968 the Supreme Court of the United States declared unconstitutional any law banning the teaching of evolution in public schools. After that time Christian fundamentalists introduced bills in a number of state legislatures ordering that the teaching of "evolution science" be balanced by allocating equal time to creation science. Creation science maintains that all kinds of organisms abruptly came into existence when God created the universe, that the world is only a few thousand years old, and that the biblical Flood was an actual event that only one pair of each animal species survived. In the 1980s Arkansas and Louisiana passed acts requiring the balanced treatment of evolution science and creation science in their schools, but opponents successfully challenged the acts as violations of the constitutionally mandated separation of church and state. The Arkansas statute was declared unconstitutional in federal court after a public trial in Little Rock. The Louisiana law was appealed all the way to the Supreme Court of the United States, which ruled Louisiana's "Creationism Act" unconstitutional because, by advancing the religious belief that a supernatural being created humankind, which is embraced by the phrase *creation science*, the act impermissibly endorses religion.

INTELLIGENT DESIGN AND ITS CRITICS

William Paley's *Natural Theology*, the book by which he has become best known to posterity, is a sustained argument explaining the obvious design of humans and their parts, as well as the design of all sorts of organisms, in

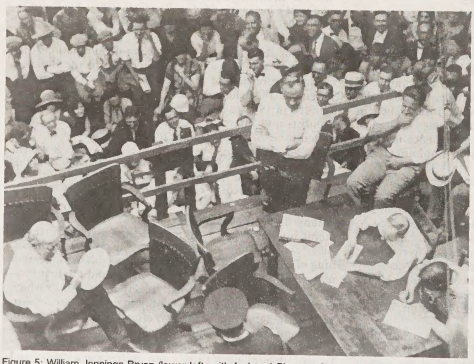

Figure 5: William Jennings Bryan (lower left, with fan) and Clarence Darrow (centre right, arms folded) in a Dayton, Tenn., courtroom during the Scopes trial, July 1925.
Library of Congress, Washington, D.C.

themselves and in their relations to one another and to their environment. Paley's keystone claim is that "there cannot be design without a designer; contrivance, without a contriver; order, without choice;... means suitable to an end, and executing their office in accomplishing that end, without the end ever having been contemplated." His book has chapters dedicated to the complex design of the human eye; to the human frame, which, he argues, displays a precise mechanical arrangement of bones, cartilage, and joints; to the circulation of the blood and the disposition of blood vessels; to the comparative anatomy of humans and animals; to the digestive system, kidneys, urethra, and bladder; to the wings of birds and the fins of fish; and much more. For more than 300 pages, Paley conveys extensive and accurate biological knowledge in such detail and precision as was available in 1802, the year of the book's publication. After his meticulous description of each biological object or process, Paley draws again and again the same conclusion—only an omniscient and omnipotent deity could account for these marvels and for the enormous diversity of inventions that they entail.

Paley's example of the human eye

On the example of the human eye he wrote:

> I know no better method of introducing so large a subject, than that of comparing... an eye, for example, with a telescope. As far as the examination of the instrument goes, there is precisely the same proof that the eye was made for vision, as there is that the telescope was made for assisting it. They are made upon the same principles; both being adjusted to the laws by which the transmission and refraction of rays of light are regulated.... For instance, these laws require, in order to produce the same effect, that the rays of light, in passing from water into the eye, should be refracted by a more convex surface than when it passes out of air into the eye. Accordingly we find that the eye of a fish, in that part of it called the crystalline lens, is much rounder than the eye of terrestrial animals. What plainer manifestation of design can there be than this difference? What could a mathematical instrument maker have done more to show his knowledge of [t]his principle, his application of that knowledge, his suiting of his means to his end... to testify counsel, choice, consideration, purpose?

It would be absurd to suppose, he argued, that by mere chance the eye

> should have consisted, first, of a series of transparent lenses—very different, by the by, even in their substance, from the opaque materials of which the rest of the body is, in general at least, composed, and with which the whole of its surface, this single portion of it excepted, is covered: secondly, of a black cloth or canvas—the only membrane in the body which is black—spread out behind these lenses, so as to receive the image formed by pencils of light transmitted through them; and placed at the precise geometrical distance at which, and at which alone, a distinct image could be formed, namely, at the concourse of the refracted rays: thirdly, of a large nerve communicating between this membrane and the brain; without which, the action of light upon the membrane, however modified by the organ, would be lost to the purposes of sensation.

The strength of the argument against chance derived, according to Paley, from a notion that he named *relation* and that later authors would term *irreducible complexity*. Paley wrote:

> When several different parts contribute to one effect, or, which is the same thing, when an effect is produced by the joint action of different instruments, the fitness of such parts or instruments to one another for the purpose of producing, by their united action, the effect, is what I call relation; and wherever this is observed in the works of nature or of man, it appears to me to carry along with it decisive evidence of understanding, intention, art... all depending upon the motions within, all upon the system of intermediate actions.

Natural Theology was part of the canon at Cambridge for half a century after Paley's death. It thus was read by Darwin, who was an undergraduate student there between 1827 and 1831, with profit and "much delight." Darwin was mindful of Paley's relation argument when in the *Origin of Species* he stated:

> If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down. But I can find out no such case.... We should be extremely cautious in concluding that an organ could not have been formed by transitional gradations of some kind.

Revival of the theory of intelligent design

In the 1990s several authors revived the argument from design. The proposition, once again, was that living beings manifest "intelligent design"—they are so diverse and complicated that they can be explained not as the outcome of natural processes but only as products of an "intelligent designer." Some authors clearly equated this entity with the God of Christianity and other monotheistic religions. Others, because they wished to see the theory of intelligent design taught in schools as an alternate to the theory of evolution, avoided all explicit reference to God in order to maintain the separation between religion and state.

The call for an intelligent designer is predicated on the existence of irreducible complexity in organisms. In Michael Behe's book *Darwin's Black Box: The Biochemical Challenge to Evolution* (1996), an irreducibly complex system is defined as being "composed of several well-matched, interacting parts that contribute to the basic function, wherein the removal of any one of the parts causes the system to effectively cease functioning." Contemporary intelligent-design proponents have argued that irreducibly complex systems cannot be the outcome of evolution. According to Behe, "Since natural selection can only choose systems that are already working, then if a biological system cannot be produced gradually it would have to arise as an integrated unit, in one fell swoop, for natural selection to have anything to act on." In other words, unless all parts of the eye come simultaneously into existence, the eye cannot function; it does not benefit a precursor organism to have just a retina, or a lens, if the other parts are lacking. The human eye, they conclude, could not have evolved one small step at a time, in the piecemeal manner by which natural selection works.

The theory of intelligent design has encountered many critics, not only among evolutionary scientists but also among theologians and religious authors. Evolutionists point out that organs and other components of living beings are not irreducibly complex—they do not come about suddenly, or in one fell swoop. The human eye did not appear suddenly in all its present complexity. Its formation required the integration of many genetic units, each improving the performance of preexisting, functionally less-perfect eyes. About 700 million years ago, the ancestors of today's vertebrates already had organs sensitive to light. Mere perception of light—and, later, various levels of vision ability—were beneficial to these organisms living in environments pervaded by sunlight. As is discussed more fully below in the section *The science of evolution: Patterns and rates of species evolution: Diversity and extinction*, different kinds of eyes have independently evolved at least 40 times in animals, which exhibit a full range, from very uncomplicated modifications that allow individual cells or simple animals to perceive the direction of light to the sophisticated vertebrate eye, passing through all sorts of organs intermediate in complexity. Evolutionists have shown that the examples of irreducibly complex systems cited by intelligent-design theorists—such as the biochemical mechanism of blood clotting or the molecular rotary motor, called the flagellum, by which bacterial cells move—are not irreducible at all; rather, less-complex versions of the same systems can be found in today's organisms.

Imperfections and defects in the living world

Evolutionists have pointed out as well that imperfections and defects pervade the living world. In the human eye, for example, the visual nerve fibres in the eye converge on an area of the retina to form the optic nerve and thus create a blind spot; squids and octopuses do not have this defect. Defective design seems incompatible with an omnipotent intelligent designer. Anticipating this criticism, Paley responded that "apparent blemishes... ought to be referred to some cause, though we be ignorant of it." Modern intelligent-design theorists have made similar assertions; according to Behe, "The argument from imperfection overlooks the possibility that the designer might have multiple motives, with engineering excellence oftentimes relegated to a secondary role." This statement, evolutionists have responded, may have theological validity, but it destroys intelligent design as a scientific hypothesis, because it provides it with an empirically impenetrable shield against predictions of how "intelligent" or "perfect" a design will

be. Science tests its hypotheses by observing whether predictions derived from them are the case in the observable world. A hypothesis that cannot be tested empirically—that is, by observation or experiment—is not scientific. The implication of this line of reasoning for U.S. public schools has been recognized not only by scientists but also by nonscientists, including politicians and policy makers. The liberal U.S. senator Edward Kennedy wrote in 2002 that "intelligent design is not a genuine scientific theory and, therefore, has no place in the curriculum of our nation's public school science classes."

Scientists, moreover, have pointed out that not only do imperfections exist but so too do dysfunctions, blunders, oddities, and cruelties prevail in the world of life. For this reason theologians and religious authors have criticized the theory of intelligent design, because it leads to conclusions about the nature of the designer at odds with the omniscience, omnipotence, and omnibenevolence that they, like Paley, identify as the attributes of the Creator. One example of a "blunder" is the human jaw, which for its size has too many teeth; the third molars, or wisdom teeth, often become impacted and need to be removed. Whereas many people would find it awkward, to say the least, to attribute to God a design that a capable human engineer would not even wish to claim, evolution gives a good account of this imperfection. As brain size increased over time in human ancestors, the concurrent remodeling of the skull entailed a reduction of the jaw so that the head of the fetus would continue to fit through the birth canal of the adult female. Evolution responds to an organism's needs not by optimal design but by tinkering, as it were—by slowly modifying existing structures through natural selection. Despite the modifications to the human jaw, the woman's birth canal remains much too narrow for easy passage of the fetal head, and many thousands of babies die during delivery as a result. Science makes this understandable as a consequence of the evolutionary enlargement of the human brain; females of other animals do not experience this difficulty.

"Blunder" of the human jaw

The world of life abounds in "cruel" behaviours. Numerous predators eat their prey alive; parasites destroy their living hosts from within; in many species of spiders and insects, the females devour their mates. Religious scholars in the past had struggled with such dysfunction and cruelty because they were difficult to explain by God's design. Evolution, in one respect, came to their rescue. A contemporary Protestant theologian called Darwin the "disguised friend," and a Roman Catholic theologian wrote of "Darwin's gift to theology." Both were acknowledging the irony that the theory of evolution, which at first had seemed to remove the need for God in the world, now was convincingly removing the need to explain the world's imperfections as outcomes of God's design.

THE SCIENCE OF EVOLUTION

The process of evolution

EVOLUTION AS A GENETIC FUNCTION

The concept of natural selection. The central argument of Darwin's theory of evolution starts with the existence of hereditary variation. Experience with animal and plant breeding had demonstrated to Darwin that variations can be developed that are "useful to man." So, he reasoned, variations must occur in nature that are favourable or useful in some way to the organism itself in the struggle for existence. Favourable variations are ones that increase chances for survival and procreation. Those advantageous variations are preserved and multiplied from generation to generation at the expense of less-advantageous ones. This is the process known as natural selection. The outcome of the process is an organism that is well adapted to its environment, and evolution often occurs as a consequence.

Natural selection, then, can be defined as the differential reproduction of alternative hereditary variants, determined by the fact that some variants increase the likelihood that the organisms having them will survive and reproduce more successfully than will organisms carrying alternative variants. Selection may occur as a result of differences in survival, in fertility, in rate of development, in mating success, or in any other aspect of the life cycle. All of these differences can be incorporated under the term *differential reproduction* because all result in natural selection to the extent that they affect the number of progeny an organism leaves.

Darwin maintained that competition for limited resources results in the survival of the most-effective competitors. Nevertheless, natural selection may occur not only as a result of competition but also as a result of some aspect of the physical environment, such as inclement weather. Moreover, natural selection would occur even if all the members of a population died at the same age, simply because some of them would have produced more offspring than others. Natural selection is quantified by a measure called Darwinian fitness, or relative fitness. Fitness in this sense is the relative probability that a hereditary characteristic will be reproduced; that is, the degree of fitness is a measure of the reproductive efficiency of the characteristic.

Darwinian fitness

Biological evolution is the process of change and diversification of living things over time, and it affects all aspects of their lives—morphology (form and structure), physiology, behaviour, and ecology. Underlying these changes are changes in the hereditary materials. Hence, in genetic terms evolution consists of changes in the organism's hereditary makeup.

Evolution can be seen as a two-step process. First, hereditary variation takes place; second, selection is made of those genetic variants that will be passed on most effectively to the following generations. Hereditary variation also entails two mechanisms—the spontaneous mutation of one variant into another and the sexual process that recombines those variants to form a multitude of variations. The variants that arise by mutation or recombination are not transmitted equally from one generation to another. Some may appear more frequently because they are favourable to the organism; the frequency of others may be determined by accidents of chance, called genetic drift.

Genetic variation in populations. *The gene pool.* The gene pool is the sum total of all of the genes and combinations of genes that occur in a population of organisms of the same species. It can be described by citing the frequencies of the alternative genetic constitutions. Consider, for example, a particular gene (which geneticists call a locus), such as the one determining the MN blood groups in humans. One form of the gene codes for the M blood group, while the other form codes for the N blood group; different forms of the same gene are called alleles. The MN gene pool of a particular population is specified by giving the frequencies of the alleles *M* and *N*. Thus, in the United States the *M* allele occurs in people of European descent with a frequency of 0.539 and the *N* allele with a frequency of 0.461—that is, 53.9 percent of the alleles in the population are *M* and 46.1 percent are *N*. In other populations these frequencies are different; for instance, the frequency of the *M* allele is 0.917 in Navajo Indians and 0.178 in Australian Aboriginals.

The necessity of hereditary variation for evolutionary change to occur can be understood in terms of the gene pool. Assume, for instance, a population in which there is no variation at the gene locus that codes for the MN blood groups; only the *M* allele exists in all individuals. Evolution of the MN blood groups cannot take place in such a population, since the allelic frequencies have no opportunity to change from generation to generation. On the other hand, in populations in which both alleles *M* and *N* are present, evolutionary change is possible.

Genetic variation and rate of evolution. The more genetic variation that exists in a population, the greater the opportunity for evolution to occur. As the number of gene loci that are variable increases and as the number of alleles at each locus becomes greater, the likelihood grows that

some alleles will change in frequency at the expense of their alternates. The British geneticist R.A. Fisher mathematically demonstrated a direct correlation between the amount of genetic variation in a population and the rate of evolutionary change by natural selection. This demonstration is embodied in his fundamental theorem of natural selection (1930): "The rate of increase in fitness of any organism at any time is equal to its genetic variance in fitness at that time."

Experimental confirmation of Fisher's theorem

This theorem has been confirmed experimentally. One study employed different strains of *Drosophila serrata*, a species of vinegar fly from eastern Australia and New Guinea. Evolution in vinegar flies can be investigated by breeding them in separate "population cages" and finding out how populations change over many generations. Experimental populations were set up, with the flies living and reproducing in their isolated microcosms. Single-strain populations were established from flies collected either in New Guinea or in Australia; in addition, a mixed population was constituted by crossing these two strains of flies. The mixed population had the greater initial genetic variation, since it began with two different single-strain populations. To encourage rapid evolutionary change, the populations were manipulated such that the flies experienced intense competition for food and space. Adaptation to the experimental environment was measured by periodically counting the number of individuals in the populations.

Two results deserve notice. First, the mixed population had, at the end of the experiment, more flies than the single-strain populations. Second, and more relevant, the number of flies increased at a faster rate in the mixed population than in the single-strain populations. Evolutionary adaptation to the environment occurred in both types of population; both were able to maintain higher numbers as the generations progressed. But the rate of evolution was more rapid in the mixed group than in the single-strain groups. The greater initial amount of genetic variation made possible a faster rate of evolution.

Measuring gene variability. Because a population's potential for evolving is determined by its genetic variation, evolutionists are interested in discovering the extent of such variation in natural populations. It is readily apparent that plant and animal species are heterogeneous in all sorts of ways—in the flower colours and growth habits of plants, for instance, or the shell shapes and banding patterns of snails. Differences are more readily noticed among humans—in facial features, hair and skin colour, height, and weight—but such morphological differences are present in all groups of organisms. One problem with morphological variation is that it is not known how much is due to genetic factors and how much may result from environmental influences.

Animal and plant breeders select for their experiments individuals or seeds that excel in desired attributes—in the protein content of corn (maize), for example, or the milk yield of cows. The selection is repeated generation after generation. If the population changes in the direction favoured by the breeder, it becomes clear that the original stock possessed genetic variation with respect to the selected trait.

The results of artificial selection are impressive. Selection for high oil content in corn increased the oil content from less than 5 percent to more than 19 percent in 76 generations, while selection for low oil content reduced it to below 1 percent. Thirty years of selection for increased egg production in a flock of White Leghorn chickens increased the average yearly output of a hen from 125.6 to 249.6 eggs. Artificial selection has produced endless varieties of dog, cat, and horse breeds. The plants grown for food and fibre and the animals bred for food and transportation are all products of age-old or modern-day artificial selection. Since the late 20th century, scientists have used the techniques of molecular biology to modify or introduce genes for desired traits in a variety of organisms, including domestic plants and animals; this field has become known as genetic engineering or recombinant DNA technology. Improvements that in the past were achieved after tens of generations by artificial selection can now be accomplished much more effectively and rapidly (within a single generation) by molecular genetic technology.

The success of artificial selection for virtually every trait and every organism in which it has been tried suggests that genetic variation is pervasive throughout natural populations. But evolutionists like to go one step farther and obtain quantitative estimates. Only since the 1960s, with the advances of molecular biology, have geneticists developed methods for measuring the extent of genetic variation in populations or among species of organisms. These methods consist essentially of taking a sample of genes and finding out how many are variable and how variable each one is. One simple way of measuring the variability of a gene locus is to ascertain what proportion of the individuals in a population are heterozygotes at that locus. In a heterozygous individual, the two genes for a trait, one received from the mother and the other from the father, are different. The proportion of heterozygotes in the population is, therefore, the same as the probability that two genes taken at random from the gene pool are different.

Methods for measuring genetic variation

Techniques for determining heterozygosity have been used to investigate numerous species of plants and animals. Typically, insects and other invertebrates are more varied genetically than mammals and other vertebrates, and plants bred by outcrossing (crossing with relatively unrelated strains) exhibit more variation than those bred by self-pollination. But the amount of genetic variation is in any case astounding. Consider as an example humans, whose level of variation is about the same as that of other mammals. The human heterozygosity value at the level of proteins is stated as $H = 0.067$, which means that an individual is heterozygous at 6.7 percent of his or her genes, because the two genes at each locus encode slightly different proteins. The Human Genome Project demonstrated that there are at least 30,000 genes in humans. This means that a person is heterozygous at no fewer than $30{,}000 \times 0.067 = 2{,}010$ gene loci. An individual heterozygous at one locus (*Aa*) can produce two different kinds of sex cells, or gametes, one with each allele (*A* and *a*); an individual heterozygous at two loci (*AaBb*) can produce four kinds of gametes (*AB*, *Ab*, *aB*, and *ab*); an individual heterozygous at n loci can potentially produce 2^n different gametes. Therefore, a typical human individual has the potential to produce $2^{2{,}010}$, or approximately 10^{605} (1 with 605 zeros following), different kinds of gametes. That number is much larger than the estimated number of atoms in the universe, about 10^{80}.

Genetic uniqueness of human individuals

It is clear, then, that every sex cell produced by a human being is genetically different from every other sex cell and, therefore, that no two persons who ever existed or will ever exist are likely to be genetically identical—with the exception of identical twins, which develop from a single fertilized ovum. The same conclusion applies to all organisms that reproduce sexually; every individual represents a unique genetic configuration that will likely never be repeated again. This enormous reservoir of genetic variation in natural populations provides virtually unlimited opportunities for evolutionary change in response to the environmental constraints and the needs of the organisms.

The origin of genetic variation: mutations. Life originated about 3.5 billion years ago in the form of primordial organisms that were relatively simple and very small. All living things have evolved from these lowly beginnings. At present there are more than two million known species, which are widely diverse in size, shape, and way of life, as well as in the DNA sequences that contain their genetic information. What has produced the pervasive genetic variation within natural populations and the genetic differences among species? There must be some evolutionary means by which existing DNA sequences are changed and new sequences are incorporated into the gene pools of species.

The information encoded in the nucleotide sequence of DNA is, as a rule, faithfully reproduced during replication, so that each replication results in two DNA molecules that are identical to each other and to the parent molecule. But heredity is not a perfectly conservative process; otherwise, evolution could not have taken place. Occasionally "mistakes," or mutations, occur in the DNA molecule during

replication, so that daughter cells differ from the parent cells in the sequence or in the amount of DNA. A mutation first appears in a single cell of an organism, but it is passed on to all cells descended from the first. Mutations can be classified into two categories—gene, or point, mutations, which affect only a few nucleotides within a gene, and chromosomal mutations, which either change the number of chromosomes or change the number or arrangement of genes on a chromosome.

Gene mutations. A gene mutation occurs when the nucleotide sequence of the DNA is altered and a new sequence is passed on to the offspring. The change may be either a substitution of one or a few nucleotides for others or an insertion or deletion of one or a few nucleotides.

Nucleotide substitutions

The four nucleotide bases of DNA, named adenine, cytosine, guanine, and thymine, are represented by the letters A, C, G, and T, respectively. A gene that bears the code for constructing a protein molecule consists of a sequence of several thousand nucleotides, so that each segment of three nucleotides—called a triplet or codon—codes for one particular amino acid in the protein. The nucleotide sequence in the DNA is first transcribed into a molecule of messenger RNA (ribonucleic acid). The RNA, using a slightly different code (represented by the letters A, C, G, and U, the last letter representing the nucleotide base uracil), bears the message that determines which amino acid will be inserted into the protein's chain in the process of translation. Substitutions in the nucleotide sequence of a structural gene may result in changes in the amino-acid sequence of the protein, although this is not always the case. The genetic code is redundant in that different triplets may hold the code for the same amino acid. Consider the triplet AUA in messenger RNA, which codes for the amino acid isoleucine. If the last A is replaced by C, the triplet still codes for isoleucine, but if it is replaced by G, it codes for methionine instead (Figure 6).

A nucleotide substitution in the DNA that results in an amino-acid substitution in the corresponding protein may or may not severely affect the biological function of the protein. Some nucleotide substitutions change a codon for an amino acid into a signal to terminate translation, and those mutations are likely to have harmful effects. If, for instance, the second U in the triplet UUA, which codes for leucine, is replaced by A, the triplet becomes UAA, a "terminator" codon; the result is that the triplets following this codon in the DNA sequence are not translated into amino acids.

Effect of nucleotide substitutions on codons for amino acids

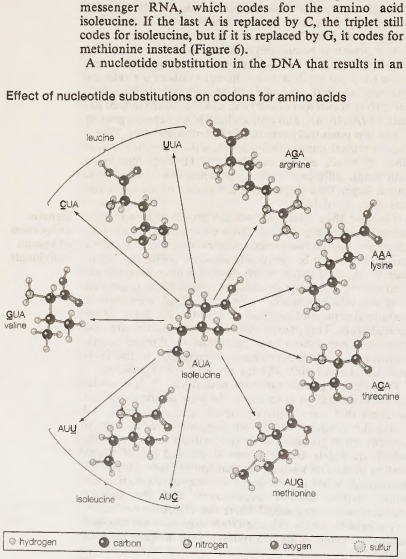

Figure 6: The effect of base substitutions on the messenger-RNA codon AUA, which codes for the amino acid isoleucine. Substitutions at the first, second, or third position in the codon can result in nine new codons corresponding to six different amino acids. The chemical properties of some of these amino acids are quite different from those of isoleucine. Substitution of a different amino acid in a protein can seriously affect its biological function.

Additions or deletions of nucleotides within the DNA sequence of a structural gene often result in a greatly altered sequence of amino acids in the coded protein. The addition or deletion of one or two nucleotides shifts the "reading frame" of the nucleotide sequence all along the way from the point of the insertion or deletion to the end of the molecule. To illustrate, assume that the DNA segment ...CATCATCATCATCAT... is read in groups of three as ...CAT-CAT-CAT-CAT-CAT.... If a nucleotide base, say T, is inserted after the first C of the segment, the segment will then be read as...CTA-TCA-TCA-TCA-TCA.... From the point of the insertion onward, the sequence of encoded amino acids is altered. If, however, a total of three nucleotides is either added or deleted, the original reading frame will be maintained in the rest of the sequence. Additions or deletions of nucleotides in numbers other than three or multiples of three are called frameshift mutations.

Shifts in the reading frame

Gene mutations can occur spontaneously—that is, without being intentionally caused by humans. They can also be induced by ultraviolet light, X rays, and other high-frequency electromagnetic radiation, as well as by exposure to certain mutagenic chemicals, such as mustard gas. The consequences of gene mutations may range from negligible to lethal. Mutations that change one or even several amino acids may have a small or undetectable effect on the organism's ability to survive and reproduce if the essential biological function of the coded protein is not hindered. But where an amino-acid substitution affects the active site of an enzyme or modifies in some other way an essential function of a protein, the impact may be severe.

Newly arisen mutations are more likely to be harmful than beneficial to their carriers, because mutations are random events with respect to adaptation—that is, their occurrence is independent of any possible consequences. The allelic variants present in an existing population have already been subject to natural selection. They are present in the population because they improve the adaptation of their carriers, and their alternative alleles have been eliminated or kept at low frequencies by natural selection. A newly arisen mutant is likely to have been preceded by an identical mutation in the previous history of a population. If the previous mutant no longer exists in the population, it is a sign that the new mutant is not beneficial to the organism and is likely also to be eliminated.

This proposition can be illustrated with an analogy. Consider a sentence whose words have been chosen because together they express a certain idea. If single letters or words are replaced with others at random, most changes will be unlikely to improve the meaning of the sentence; very likely they will destroy it. The nucleotide sequence of a gene has been "edited" into its present form by natural selection because it "makes sense." If the sequence is changed at random, the "meaning" rarely will be improved and often will be hampered or destroyed.

Consequences depend on the environment

Occasionally, however, a new mutation may increase the organism's adaptation. The probability of such an event's happening is greater when organisms colonize a new territory or when environmental changes confront a population with new challenges. In these cases the established adaptation of a population is less than optimal, and there is greater opportunity for new mutations to be better adaptive. The consequences of mutations depend on the environment. Increased melanin pigmentation may be advantageous to inhabitants of tropical Africa, where dark skin protects them from the Sun's ultraviolet radiation, but it is not beneficial in Scandinavia, where the intensity of sunlight is low and light skin facilitates the synthesis of vitamin D.

Mutation rates have been measured in a great variety of organisms, mostly for mutants that exhibit conspicuous effects. Mutation rates are generally lower in bacteria and other microorganisms than in more complex species. In humans and other multicellular organisms, the rate typically ranges from about 1 per 100,000 to 1 per 1,000,000 gametes. There is, however, considerable variation from gene to gene as well as from organism to organism.

Although mutation rates are low, new mutants appear continuously in nature, because there are many individuals in every species and many gene loci in every individual. The process of mutation provides each generation with many new genetic variations. Thus, it is not surprising to see that when new environmental challenges arise, species are able to adapt to them. More than 200 insect and rodent species, for example, have developed resistance to the pesticide DDT in parts of the world where spraying has been intense. Although these animals had never before encountered this synthetic compound, they adapted to it rapidly by means of mutations that allowed them to survive in its presence. Similarly, many species of moths and butterflies in industrialized regions have shown an increase in the frequency of individuals with dark wings in response to environmental pollution, an adaptation known as industrial melanism (see below *The operation of natural selection in populations: Types of selection: Directional selection*).

Drug resistance in disease-causing microorganisms

The resistance of disease-causing bacteria and parasites to antibiotics and other drugs is a consequence of the same process. When an individual receives an antibiotic that specifically kills the bacteria causing the disease, say, tuberculosis, the immense majority of the bacteria die, but one in a million may have a mutation that provides resistance to the antibiotic. These bacteria will survive, multiply, and no longer be susceptible to the antibiotic. This is the reason that modern medicine treats bacterial diseases with cocktails of antibiotics. If the incidence of a mutation conferring resistance for a given antibiotic is one in a million, the incidence of one bacterium carrying three mutations, each conferring resistance to one of three antibiotics, is one in a trillion; such bacteria are far less likely to exist in any infected individual.

Chromosomal mutations. Chromosomes, which carry the hereditary material, or DNA, are contained in the nucleus of each cell. Chromosomes come in pairs, with one member of each pair inherited from each parent. The two members of a pair are called homologous chromosomes. Each cell of an organism and all individuals of the same species have, as a rule, the same number of chromosomes. The reproductive cells (gametes) are an exception; they have only half as many chromosomes as the body (somatic) cells. But the number, size, and organization of chromosomes varies between species. The parasitic nematode *Parascaris univalens* has only one pair of chromosomes, whereas many species of butterflies have more than 100 pairs and some ferns more than 600. Even closely related organisms may vary considerably in the number of chromosomes. Species of spiny rats of the South American genus *Proechimys* range from 12 to 31 chromosome pairs.

Changes in the number, size, or organization of chromosomes within a species are termed chromosomal mutations, chromosomal abnormalities, or chromosomal aberrations. Changes in number may occur by the fusion of two chromosomes into one, by fission of one chromosome into two, or by addition or subtraction of one or more whole chromosomes or sets of chromosomes. (The condition in which an organism acquires one or more additional sets of chromosomes is called polyploidy.) Changes in the structure of chromosomes may occur by inversion, when a chromosomal segment rotates 180 degrees within the same location; by duplication, when a segment is added; by deletion, when a segment is lost; or by translocation, when a segment changes from one location to another in the same or a different chromosome. These are the

Changes to gene linkages

processes by which chromosomes evolve. Inversions, translocations, fusions, and fissions do not change the amount of DNA. The importance of these mutations in evolution is that they change the linkage relationships between genes. Genes that were closely linked to each other become separated and vice versa; this can affect their expression because genes are often transcribed sequentially, two or more at a time.

DYNAMICS OF GENETIC CHANGE

Genetic equilibrium: the Hardy-Weinberg law. Genetic variation is present throughout natural populations of organisms. This variation is sorted out in new ways in each generation by the process of sexual reproduction, which recombines the chromosomes inherited from the two parents during the formation of the gametes that produce the following generation. But heredity by itself does not change gene frequencies. This principle is stated by the Hardy-Weinberg law, so called because it was independently discovered in 1908 by the English mathematician G.H. Hardy and the German physician Wilhelm Weinberg.

The Hardy-Weinberg law describes the genetic equilibrium in a population by means of an algebraic equation. It states that genotypes—the genetic constitution of individual organisms—exist in certain frequencies that are a simple function of the allelic frequencies—namely, the square expansion of the sum of the allelic frequencies.

If there are two alleles, A and a, at a gene locus, three genotypes will be possible: AA, Aa, and aa. If the frequencies of the alleles A and a are p and q, respectively, the equilibrium frequencies of the three genotypes will be given by $(p + q)^2 = p^2 + 2pq + q^2$ for AA, Aa, and aa, respectively. The genotype equilibrium frequencies for any number of alleles are derived in the same way. If there are three alleles, A_1, A_2, and A_3, with frequencies p, q, and r, the equilibrium frequencies corresponding to the six possible genotypes (shown in parentheses) will be calculated as follows:

$$(p + q + r)^2 = p^2(A_1A_1) + q^2(A_2A_2) + r^2(A_3A_3) + 2pq(A_1A_2) + 2pr(A_1A_3) + 2qr(A_2A_3).$$

Table 1 shows how the law operates in a situation with just two alleles. At the top and to the left are the frequencies in the parental generation of the two alleles, p for A and q for a. As shown at the lower right, the probabilities of the three possible genotypes in the following generation are products of the probabilities of the corresponding alleles in the parents. The probability of genotype AA among the progeny is the probability p that allele A will be present in the paternal gamete multiplied by the probability p that allele A will be present in the maternal gamete, or p^2. Similarly, the probability of the genotype aa is q^2. The genotype Aa can arise when A from the father combines with a from the mother, which will occur with a frequency pq, or when a from the father combines with A from the mother, which also has a probability of pq; the result is a total probability of $2pq$ for the frequency of the Aa genotype in the progeny.

Table 1: The Hardy-Weinberg Law Applied to Two Alleles

paternal gametic frequencies	maternal gametic frequencies	
	$p(A)$	$q(a)$
$p(A)$	$p^2(AA)$	$pq(Aa)$
$q(a)$	$pq(Aa)$	$q^2(aa)$

There is no change in the allele equilibrium frequencies from one generation to the next. The frequency of the A allele among the offspring is the frequency of the AA genotype (because all alleles in these individuals are A alleles) plus half the frequency of the Aa genotype (because half the alleles in these individuals are A alleles), or $p^2 + pq = p(p + q) = p$ (because $p + q = 1$). Similarly, the frequency of the a allele among the offspring is given by $q^2 + pq = q(q + p) = q$. These are precisely the frequencies of the alleles in the parents.

The genotype equilibrium frequencies are obtained by the Hardy-Weinberg law on the assumption that there is random mating—that is, the probability of a particular kind of mating is the same as the frequency of the genotypes of the two mating individuals. For example, the probability of an AA female mating with an aa male must be p^2 (the frequency of AA) times q^2 (the frequency of aa). Random mating can occur with respect to most gene loci even

though mates may be chosen according to particular characteristics. People, for example, choose their spouses according to all sorts of preferences concerning looks, personality, and the like. But concerning the majority of genes, people's marriages are essentially random.

Assortative, or selective, mating

Assortative, or selective, mating takes place when the choice of mates is not random. Marriages in the United States, for example, are assortative with respect to many social factors, so that members of any one social group tend to marry members of their own group more often, and people from a different group less often, than would be expected from random mating. Consider the sensitive social issue of interracial marriage in a hypothetical community in which 80 percent of the population is white and 20 percent is black. With random mating, 32 percent ($2 \times 0.80 \times 0.20 = 0.32$) of all marriages would be interracial, whereas only 4 percent ($0.20 \times 0.20 = 0.04$) would be marriages between two blacks. These statistical expectations depart from typical observations even in modern society, as a result of persistent social customs that for evolutionists are examples of assortative mating. The most extreme form of assortative mating is self-fertilization, which occurs rarely in animals but is a common form of reproduction in many plant groups.

The Hardy-Weinberg law assumes that gene frequencies remain constant from generation to generation—that there is no gene mutation or natural selection and that populations are very large. But these assumptions are not correct; indeed, if they were, evolution could not occur. Why, then, is the law significant if its assumptions do not hold true in nature? The answer is that it plays in evolutionary studies a role similar to that of Newton's first law of motion in mechanics. Newton's first law says that a body not acted upon by a net external force remains at rest or maintains a constant velocity. In fact, there are always external forces acting upon physical objects, but the first law provides the starting point for the application of other laws. Similarly, organisms are subject to mutation, selection, and other processes that change gene frequencies, but the effects of these processes can be calculated by using the Hardy-Weinberg law as the starting point.

Processes of gene-frequency change. *Mutation.* The allelic variations that make evolution possible are generated by the process of mutation, but new mutations change gene frequencies very slowly, since mutation rates are low. Assume that the gene allele A_1 mutates to allele A_2 at a rate m per generation and that at a given time the frequency of A_1 is p. In the next generation, a fraction m of all A_1 alleles become A_2 alleles. The frequency of A_1 in the next generation will then be reduced by the fraction of mutated alleles (pm), or $p_1 = p - pm = p(1-m)$. After t generations the frequency of A_1 will be $p_t = p(1-m)^t$.

If the mutations continue, the frequency of A_1 alleles will gradually decrease, because a fraction of them change every generation to A_2. If the process continues indefinitely, the A_1 allele will eventually disappear, although the process is slow. If the mutation rate is 10^{-5} (1 in 100,000) per gene per generation, about 2,000 generations will be required for the frequency of A_1 to change from 0.50 to 0.49 and about 10,000 generations for it to change from 0.10 to 0.09.

Moreover, gene mutations are reversible: the allele A_2 may also mutate to A_1. Assume that A_1 mutates to A_2 at a rate m, as before, and that A_2 mutates to A_1 at a rate n per generation. If at a certain time the frequencies of A_1 and A_2 are p and q, respectively, after one generation the frequency of A_1 will be $p_1 = p - pm + qn$. A fraction pm of allele A_1 changes to A_2, but a fraction qn of the A_2 alleles changes to A_1. The conditions for equilibrium occur when $pm = qn$, or $p = n/(m+n)$. Suppose that the mutation rates are $m = 10^{-5}$ and $n = 10^{-6}$; then, at equilibrium, $p = 10^{-6}/(10^{-5} + 10^{-6}) = 1/(10+1) = 0.09$, and $q = 0.91$.

Changes in gene frequencies due to mutation occur, therefore, at rates even slower than was suggested above, because forward and backward mutations counteract each other. In any case, allelic frequencies usually are not in mutational equilibrium, because some alleles are favoured over others by natural selection. The equilibrium frequencies are then decided by the interaction between mutation and selection, with selection usually having the greater consequence.

Gene flow. Gene flow, or gene migration, takes place when individuals migrate from one population to another and interbreed with its members. Gene frequencies are not changed for the species as a whole, but they change locally whenever different populations have different allele frequencies. In general, the greater the difference in allele frequencies between the resident and the migrant individuals, and the larger the number of migrants, the greater effect the migrants have in changing the genetic constitution of the resident population.

Suppose that a proportion of all reproducing individuals in a population are migrants and that the frequency of allele A_1 is p in the population but p_m among the migrants. The change in gene frequency, Δp, in the next generation will be $\Delta p = m(p_m - p)$. If the migration rate persists for a number t of generations, the frequency of A_1 will be given by $p_t = (1-m)^t(p - p_m) + p_m$.

Genetic drift. Gene frequencies can change from one generation to another by a process of pure chance known as genetic drift. This occurs because the number of individuals in any population is finite, and thus the frequency of a gene may change in the following generation by accidents of sampling, just as it is possible to get more or fewer than 50 "heads" in 100 throws of a coin simply by chance.

Inverse relationship to population size

The magnitude of the gene frequency changes due to genetic drift is inversely related to the size of the population—the larger the number of reproducing individuals, the smaller the effects of genetic drift. This inverse relationship between sample size and magnitude of sampling errors can be illustrated by referring again to tossing a coin. When a penny is tossed twice, two heads are not surprising. But it will be surprising, and suspicious, if 20 tosses all yield heads. The proportion of heads obtained in a series of throws approaches closer to 0.5 as the number of throws grows larger.

The relationship is the same in populations, although the important value here is not the actual number of individuals in the population but the "effective" population size. This is the number of individuals that produce offspring, because only reproducing individuals transmit their genes to the following generation. It is not unusual, in plants as well as animals, for some individuals to have large numbers of progeny while others have none. In marine seals, antelopes, baboons, and many other mammals, for example, a dominant male may keep a large harem of females at the expense of many other males who can find no mates. It often happens that the effective population size is substantially smaller than the number of individuals in any one generation.

The effects of genetic drift in changing gene frequencies from one generation to the next are quite small in most natural populations, which generally consist of thousands of reproducing individuals. The effects over many generations are more important. Indeed, in the absence of other processes of change (such as natural selection and mutation), populations would eventually become fixed, having one allele at each locus after the gradual elimination of all others. With genetic drift as the only force in operation, the probability of a given allele's eventually reaching a frequency of 1 would be precisely the frequency of the allele—that is, an allele with a frequency of 0.8 would have an 80 percent chance of ultimately becoming the only allele present in the population. The process would, however, take a long time, because increases and decreases are likely to alternate with equal probability. More important, natural selection and other processes change gene frequencies in ways not governed by pure chance, so that no allele has an opportunity to become fixed as a consequence of genetic drift alone.

The founder principle

Genetic drift can have important evolutionary consequences when a new population becomes established by only a few individuals—a phenomenon known as the founder principle. Islands, lakes, and other isolated ecological sites are often colonized by one or very few seeds or animals of a species, which are transported there passively by wind, in the fur of larger animals, or in some other way.

The allelic frequencies present in these few colonizers are likely to differ at many loci from those in the population they left, and those differences have a lasting impact on the evolution of the new population. The founder principle is one reason that species in neighbouring islands, such as those in the Hawaiian archipelago, are often more heterogeneous than species in comparable continental areas adjacent to one another.

Population bottlenecks

Climatic or other conditions, if unfavourable, may on occasion drastically reduce the number of individuals in a population and even threaten it with extinction. Such occasional reductions are called population bottlenecks. The populations may later recover their typical size, but the allelic frequencies may have been considerably altered and thereby affect the future evolution of the species. Bottlenecks are more likely in relatively large animals and plants than in smaller ones, because populations of large organisms typically consist of fewer individuals. Primitive human populations of the past were subdivided into many small tribes that were time and again decimated by disease, war, and other disasters. Differences among current human populations in the allele frequencies of many genes—such as those determining the ABO and other blood groups—may have arisen at least in part as a consequence of bottlenecks in ancestral populations. Persistent population bottlenecks may reduce the overall genetic variation so greatly as to alter future evolution and endanger the survival of the species. A well-authenticated case is that of the cheetah, where no allelic variation whatsoever has been found among the many scores of gene loci studied.

THE OPERATION OF NATURAL SELECTION IN POPULATIONS

Natural selection as a process of genetic change. Natural selection refers to any reproductive bias favouring some genes or genotypes over others. Natural selection promotes the adaptation of organisms to the environments in which they live; any hereditary variant that improves the ability to survive and reproduce in an environment will increase in frequency over the generations, precisely because the organisms carrying such a variant will leave more descendants than those lacking it. Hereditary variants, favourable or not to the organisms, arise by mutation. Unfavourable ones are eventually eliminated by natural selection; their carriers leave no descendants or leave fewer than those carrying alternative variants. Favourable mutations accumulate over the generations. The process continues indefinitely because the environments that organisms inhabit are forever changing. Environments change physically—in their climate, configuration, and so on—but also biologically, because the predators, parasites, competitors, and food sources with which an organism interacts are themselves evolving.

Mutation, gene flow, and genetic drift are random processes with respect to adaptation; they change gene frequencies without regard for the consequences that such changes may have in the ability of the organisms to survive and reproduce. If these were the only processes of evolutionary change, the organization of living things would gradually disintegrate. The effects of such processes alone would be analogous to those of a mechanic who changed parts in an automobile engine at random, with no regard for the role of the parts in the engine. Natural selection keeps the disorganizing effects of mutation and other processes in check because it multiplies beneficial mutations and eliminates harmful ones.

Natural selection accounts not only for the preservation and improvement of the organization of living beings but also for their diversity. In different localities or in different circumstances, natural selection favours different traits, precisely those that make the organisms well adapted to their particular circumstances and ways of life.

Calculation of relative fitness values

The parameter used to measure the effects of natural selection is fitness (see above the section *The concept of natural selection*), which can be expressed as an absolute or as a relative value. Consider a population consisting at a certain locus of three genotypes: A_1A_1, A_1A_2, and A_2A_2. Assume that on the average each A_1A_1 and each A_1A_2 individual produces one offspring but that each A_2A_2 individual produces two. One could use the average number of progeny left by each genotype as a measure of that genotype's absolute fitness and calculate the changes in gene frequency that would occur over the generations. (This, of course, requires knowing how many of the progeny survive to adulthood and reproduce.) Evolutionists, however, find it mathematically more convenient to use relative fitness values—which they represent with the letter w—in most calculations. They usually assign the value 1 to the genotype with the highest reproductive efficiency and calculate the other relative fitness values proportionally. For the example just used, the relative fitness of the A_2A_2 genotype would be $w = 1$ and that of each of the other two genotypes would be $w = 0.5$. A parameter related to fitness is the selection coefficient, often represented by the letter s, which is defined as $s = 1 - w$. The selection coefficient is a measure of the reduction in fitness of a genotype. The selection coefficients in the example are $s = 0$ for A_2A_2 and $s = 0.5$ for A_1A_1 and for A_1A_2.

The different ways in which natural selection affects gene frequencies are illustrated by the following examples.

Relationship to recessive diseases

Selection against one of the homozygotes. Suppose that one homozygous genotype, say A_2A_2, has lower fitness than the other two genotypes, A_1A_1 and A_1A_2. (This is the situation in many human diseases, such as phenylketonuria [PKU] and sickle cell anemia, that are inherited in a recessive fashion and that require the presence of two deleterious mutant alleles for the trait to manifest.) The heterozygotes and the homozygotes for the normal allele (A_1) have equal fitness, higher than that of the homozygotes for the deleterious mutant allele (A_2). Call the fitness of these latter homozygotes $1 - s$ (the fitness of the other two genotypes is 1), and let p be the frequency of A_1 and q the frequency of A_2. It can be shown that the frequency of A_2 will decrease each generation by an amount given by $\Delta q = -spq^2/(1 - sq^2)$. The deleterious allele will continuously decrease in frequency until it has been eliminated. The rate of elimination is fastest when $s = 1$ (*i.e.*, when the relative fitness $w = 0$); this occurs with fatal diseases, such as untreated PKU, when the homozygotes die before the age of reproduction.

Because of new mutations, the elimination of a deleterious allele is never complete. A dynamic equilibrium frequency will exist when the number of new alleles produced by mutation is the same as the number eliminated by selection. If the mutation rate at which the deleterious allele arises is u, the equilibrium frequency for a deleterious allele that is recessive is given approximately by $q = \sqrt{u/s}$, which, if $s = 1$, reduces to $q = \sqrt{u}$.

The mutation rate for many human recessive diseases is about 1 in 100,000 ($u = 10^{-5}$). If the disease is fatal, the equilibrium frequency becomes $q \approx \sqrt{10^{-5}} = 0.003$, or about 1 recessive lethal mutant allele for every 300 normal alleles. That is roughly the frequency in human populations of alleles that in homozygous individuals, such as those with PKU, cause death before adulthood. The equilibrium frequency for a deleterious, but not lethal, recessive allele is much higher. Albinism, for example, is due to a recessive gene. The reproductive efficiency of albinos is, on average, about 0.9 that of normal individuals. Therefore, $s = 0.1$ and $q = \sqrt{u/s} = \sqrt{10^{-5}/10^{-1}} = 0.01$, or 1 in 100 genes rather than 1 in 300 as for a lethal allele.

For deleterious dominant alleles, the mutation-selection equilibrium frequency is given by $p = u/s$, which for fatal genes becomes $p = u$. If the gene is lethal even in single copy, all the genes are eliminated by selection in the same generation in which they arise, and the frequency of the gene in the population is the frequency with which it arises by mutation. One deleterious condition that is caused by a dominant allele present at low frequencies in human populations is achondroplasia, the most common cause of dwarfism. Because of abnormal growth of the long bones, achondroplastics have short, squat, often deformed limbs, along with bulging skulls. The mutation rate from the normal allele to the achondroplasia allele is about 5×10^{-5}. Achondroplastics reproduce only 20 percent as efficiently as normal individuals; hence, $s = 0.8$. The equilibrium frequency of the mutant allele can therefore be calculated as $p = u/s = 6.25 \times 10^{-5}$.

Overdominance. In many instances heterozygotes have a higher degree of fitness than homozygotes for one or the other allele. This situation, known as heterosis or overdominance, leads to the stable coexistence of both alleles in the population and hence contributes to the widespread genetic variation found in populations of most organisms. The model situation is:

Genotype	A_1A_1	A_1A_2	A_2A_2
Fitness (w)	$1-s$	1	$1-t$

It is assumed that s and t are positive numbers between 0 and 1, so that the fitnesses of the two homozygotes are somewhat less than 1. It is not difficult to show that the change in frequency per generation of allele A_2 is $\Delta q = pq(sp - tq)/(1 - sp^2 - tq^2)$. An equilibrium will exist when $\Delta q = 0$ (gene frequencies no longer change); this will happen when $sp = tq$, at which the numerator of the expression for Δq will be 0. The condition $sp = tq$ can be rewritten as $s(1 - q) = tq$ (when $p + q = 1$), which leads to $q = s/(s + t)$. If the fitnesses of the two homozygotes are known, it is possible to infer the allele equilibrium frequencies.

One of many well-investigated examples of overdominance in animals is the colour polymorphism that exists in the marine copepod crustacean *Tisbe reticulata*. Three populations of colour variants (morphs) are found in the lagoon of Venice; they are known as violacea (homozygous genotype V^VV^V), maculata (homozygous genotype V^MV^M), and violacea-maculata (heterozygous genotype V^VV^M). The colour polymorphism persists in the lagoon because the heterozygotes survive better than either of the two homozygotes. In laboratory experiments, the fitness of the three genotypes depends on the degree of crowding, as shown by the following comparison of their relative fitnesses:

Genotype	Fitness in low crowding	Fitness in high crowding
V^VV^V	0.89	0.66
V^VV^M	1	1
V^MV^M	0.90	0.62

The greater the crowding—with more competition for resources—the greater the superiority of the heterozygotes.

Sickle cell anemia

A particularly interesting example of heterozygote superiority among humans is provided by the gene responsible for sickle cell anemia. Human hemoglobin in adults is for the most part hemoglobin A, a four-component molecule consisting of two α and two β hemoglobin chains. The gene Hb^A codes for the normal β hemoglobin chain, which consists of 146 amino acids. A mutant allele of this gene, Hb^S, causes the β chain to have in the sixth position the amino acid valine instead of glutamic acid. This seemingly minor substitution modifies the properties of hemoglobin so that homozygotes with the mutant allele, Hb^SHb^S, suffer from a severe form of anemia that in most cases leads to death before the age of reproduction.

The Hb^S allele occurs in some African and Asian populations with a high frequency. This formerly was puzzling because the severity of the anemia, representing a strong natural selection against homozygotes, should have eliminated the defective allele. But researchers noticed that the Hb^S allele occurred at high frequency precisely in regions of the world where a particularly severe form of malaria, which is caused by the parasite *Plasmodium falciparum*, was endemic. It was hypothesized that the heterozygotes, Hb^AHb^S, were resistant to malaria, whereas the homozygotes Hb^AHb^A were not. In malaria-infested regions, therefore, the heterozygotes survived better than either of the homozygotes, which were more likely to die from either malaria (Hb^AHb^A homozygotes) or anemia (Hb^SHb^S homozygotes). This hypothesis has been confirmed in various ways. Most significant is that most hospital patients suffering from severe or fatal forms of malaria are homozygotes Hb^AHb^A. In a study of 100 children who died from malaria, only 1 was found to be a heterozygote, whereas 22 were expected to be so according to the frequency of the Hb^S allele in the population.

Table 2 shows how the relative fitness of the three β-chain genotypes can be calculated from their distribution among the Yoruba people of Ibadan, Nigeria. The frequency of the Hb^S allele among adults is estimated as $q = 0.1232$. According to the Hardy-Weinberg law, the three genotypes will be formed at conception in the frequencies p^2, $2pq$, and q^2, which are the expected frequencies given in Table 1. The ratios of the observed frequencies among adults to the expected frequencies give the relative survival efficiency of the three genotypes. These are divided by their largest value (1.12) in order to obtain the relative fitness of the genotypes. Sickle cell anemia reduces the probability of survival of the Hb^SHb^S homozygotes to 13 percent of that of the heterozygotes. On the other hand, malaria infection reduces the survival probability of the homozygotes for the normal allele, Hb^AHb^A, to 88 percent of that of the heterozygotes.

Table 2: Fitnesses of the Three Genotypes at the Sickle Cell Anemia Locus in a Population from Nigeria

	genotype				
	Hb^AHb^A	Hb^AHb^S	Hb^SHb^S	total	frequency of Hb^S
Observed number	9365	2993	29	12,387	
Observed frequency	0.7560	0.2416	0.0023	1	0.1232
Expected frequency	0.7688	0.2160	0.0152	1	0.1232
Survival efficiency	0.98	1.12	0.15		
Relative fitness	0.88	1	0.13		

Frequency-dependent selection. The fitness of genotypes can change when the environmental conditions change. White fur may be protective to a bear living on the Arctic snows but not to one living in a Russian forest; there an allele coding for brown pigmentation may be favoured over one that codes for white. The environment of an organism includes not only the climate and other physical features but also the organisms of the same or different species with which it is associated.

Effect of population density on fitness

Changes in genotypic fitness are associated with the density of the organisms present. Insects and other short-lived organisms experience enormous yearly oscillations in density. Some genotypes may possess high fitness in the spring, when the population is rapidly expanding, because such genotypes yield more prolific individuals. Other genotypes may be favoured during the summer, when populations are dense, because these genotypes make for better competitors, ones more successful at securing limited food resources. Still others may be at an advantage during the long winter months, because they increase the population's hardiness, or ability to withstand the inclement conditions that kill most members of the other genotypes.

The fitness of genotypes can also vary according to their relative numbers, and genotype frequencies may change as a consequence. This is known as frequency-dependent selection. Particularly interesting is the situation in which genotypic fitnesses are inversely related to their frequencies. Assume that two genotypes, A and B, have fitnesses related to their frequencies in such a way that the fitness of either genotype increases when its frequency decreases and vice versa. When the A genotype is rare, its fitness is high, and therefore A increases in frequency. As it becomes more and more common, however, the fitness of A gradually decreases, so that its increase in frequency eventually comes to a halt. A stable polymorphism occurs at the frequency at which the two genotypes, A and B, have identical fitnesses.

In natural populations of animals and plants, frequency-dependent selection is very common and may contribute importantly to the maintenance of genetic polymorphism. In the vinegar fly *Drosophila pseudoobscura*, for example, three genotypes exist at the gene locus that codes for the metabolically important enzyme malate dehydrogenase—the homozygous *SS* and *FF* and the heterozygous *SF*. When the *SS* homozygotes represent 90 percent of the population, they have a fitness about two-thirds that of the heterozygotes, *SF*. But when the *SS* homozygotes represent only 10 percent of the population, their fitness is more than double that of the heterozygotes. Similarly, the fitness of the *FF* homozygotes relative to the heterozygotes increases from less than half to nearly double as their frequency goes from 90 to 10 percent. All three genotypes

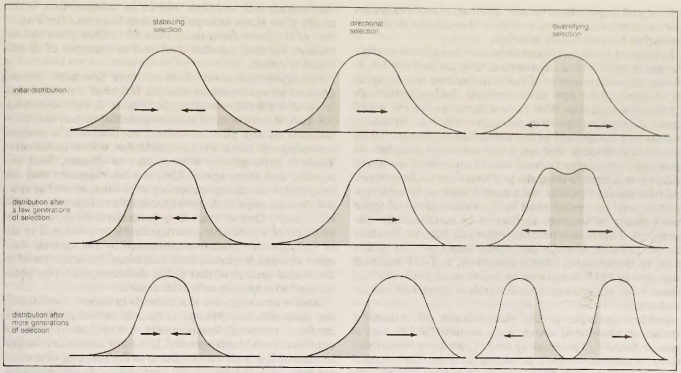

Figure 7: Three types of natural selection showing the effects of each on the distribution of phenotypes within a population. The shaded areas represent the phenotypes against which selection acts. Stabilizing selection acts against phenotypes at both extremes of the distribution, favouring the multiplication of intermediate phenotypes. Directional selection acts against only one extreme of phenotypes, causing a shift in distribution toward the other extreme. Diversifying selection acts against intermediate phenotypes, creating a split in distribution toward each extreme.

have equal fitnesses when the frequency of the *S* allele, represented by p, is about 0.70, so that there is a stable polymorphism with frequencies $p^2 = 0.49$ for *SS*, $2pq = 0.42$ for *SF*, and $q^2 = 0.09$ for *FF*.

Frequency-dependent selection may arise because the environment is heterogeneous and because different genotypes can better exploit different subenvironments. When a genotype is rare, the subenvironments that it exploits better will be relatively abundant. But as the genotype becomes common, its favoured subenvironment becomes saturated. That genotype must then compete for resources in subenvironments that are optimal for other genotypes. It follows then that a mixture of genotypes exploits the environmental resources better than a single genotype. This has been extensively demonstrated. When the three *Drosophila* genotypes mentioned above were mixed in a single population, the average number of individuals that developed per unit of food was 45.6. This was greater than the number of individuals that developed when only one of the genotypes was present, which averaged 41.1 for *SS*, 40.2 for *SF*, and 37.1 for *FF*. Plant breeders know that mixed plantings (a mixture of different strains) are more productive than single stands (plantings of one strain only), although farmers avoid them for reasons such as increased harvesting costs.

Advantage of genotype mixtures

Sexual preferences can also lead to frequency-dependent selection. It has been demonstrated in some insects, birds, mammals, and other organisms that the mates preferred are precisely those that are rare. People also appear to experience this rare-mate advantage—blonds may seem attractively exotic to brunets, or brunets to blonds.

Types of selection. *Stabilizing selection.* Natural selection can be studied by analyzing its effects on changing gene frequencies, but it can also be explored by examining its effects on the observable characteristics—or phenotypes—of individuals in a population. Distribution scales of phenotypic traits such as height, weight, number of progeny, or longevity typically show greater numbers of individuals with intermediate values and fewer and fewer toward the extremes—this is the so-called normal distribution. When individuals with intermediate phenotypes are favoured and extreme phenotypes are selected against, the selection is said to be stabilizing. (See Figure 7, left column.) The range and distribution of phenotypes then remains approximately the same from one generation to another. Stabilizing selection is very common. The individuals that survive and reproduce more successfully are those that have intermediate phenotypic values. Mortality among newborn infants, for example, is highest when they are either very small or very large; infants of intermediate size have a greater chance of surviving.

Stabilizing selection is often noticeable after artificial selection. Breeders choose chickens that produce larger eggs, cows that yield more milk, and corn with higher protein content. But the selection must be continued or reinstated from time to time, even after the desired goals have been achieved. If it is stopped altogether, natural selection gradually takes effect and turns the traits back toward their original intermediate value.

Counterforce to artificial selection

As a result of stabilizing selection, populations often maintain a steady genetic constitution with respect to many traits. This attribute of populations is called genetic homeostasis.

Directional selection. The distribution of phenotypes in a population sometimes changes systematically in a particular direction. (See Figure 7, centre column.) The physical and biological aspects of the environment are continuously changing, and over long periods of time the changes may be substantial. The climate and even the configuration of the land or waters vary incessantly. Changes also take place in the biotic conditions—that is, in the other organisms present, whether predators, prey, parasites, or competitors. Genetic changes occur as a consequence, because the genotypic fitnesses may shift so that different sets of alleles are favoured. The opportunity for directional selection also arises when organisms colonize new environments where the conditions are different from those of their original habitat. In addition, the appearance of a new favourable allele or a new genetic combination may prompt directional changes as the new genetic constitution replaces the preexisting one.

The process of directional selection takes place in spurts. The replacement of one genetic constitution with another changes the genotypic fitnesses at other loci, which then change in their allelic frequencies, thereby stimulating additional changes, and so on in a cascade of consequences.

Directional selection is possible only if there is genetic variation with respect to the phenotypic traits under selection. Natural populations contain large stores of genetic variation, and these are continuously replenished by additional new variants that arise by mutation. The nearly universal success of artificial selection and the rapid response

of natural populations to new environmental challenges are evidence that existing variation provides the necessary materials for directional selection.

In modern times human actions have been an important stimulus to this type of selection. Human activity transforms the environments of many organisms, which rapidly respond to the new environmental challenges through directional selection. Well-known instances are the many cases of insect resistance to pesticides, which are synthetic substances not present in the natural environment. When a new insecticide is first applied to control a pest, the results are encouraging because a small amount of the insecticide is sufficient to bring the pest organism under control. As time passes, however, the amount required to achieve a certain level of control must be increased again and again until finally it becomes ineffective or economically impractical. This occurs because organisms become resistant to the pesticide through directional selection. The resistance of the housefly, *Musca domestica*, to DDT was first reported in 1947. Resistance to one or more pesticides has since been recorded in several hundred species of insects and mites.

Industrial melanism

Another example is the phenomenon of industrial melanism mentioned above in the section *Evolution as a genetic function: The origin of genetic variation: mutations: Gene mutations*—which is exemplified by the gradual darkening of the wings of many species of moths and butterflies living in woodlands darkened by industrial pollution. The best-investigated case is the peppered moth, *Biston betularia*, of England. Until the middle of the 19th century, these moths were uniformly peppered light gray. Darkly pigmented variants were detected first in 1848 in Manchester and shortly afterward in other industrial regions where the vegetation was blackened by soot and other pollutants. By the middle of the 20th century, the dark varieties had almost completely replaced the lightly pigmented forms in many polluted areas, while in unpolluted regions light moths continued to be the most common. The shift from light to dark moths was an example of directional selection brought about by bird predators. On lichen-covered tree trunks, the light-gray moths are well camouflaged, whereas the dark ones are conspicuously visible and therefore fall victim to the birds. The opposite is the case on trees darkened by pollution (Figure 8).

Over geologic time, directional selection leads to major changes in morphology and ways of life. Evolutionary changes that persist in a more or less continuous fashion over long periods of time are known as evolutionary trends. Directional evolutionary changes increased the cranial capacity of the human lineage from the small brain of *Australopithecus*—human ancestors of three million years ago—which was less than 500 cc in volume, to a brain nearly three times as large in modern humans. The evolution of the horse from more than 50 million years ago to modern times is another well-studied example of directional selection.

Diversifying selection. Two or more divergent phenotypes in an environment may be favoured simultaneously by diversifying selection. (See Figure 7, right column.)

Mosaic character of natural environments

No natural environment is homogeneous; rather, the environment of any plant or animal population is a mosaic consisting of more or less dissimilar subenvironments. There is heterogeneity with respect to climate, food resources, and living space. Also, the heterogeneity may be temporal, with change occurring over time, as well as spatial. Species cope with environmental heterogeneity in diverse ways. One strategy is genetic monomorphism, the selection of a generalist genotype that is well adapted to all of the subenvironments encountered by the species. Another strategy is genetic polymorphism, the selection of a diversified gene pool that yields different genotypes, each adapted to a specific subenvironment.

There is no single plan that prevails in nature. Sometimes the most efficient strategy is genetic monomorphism to confront temporal heterogeneity but polymorphism to confront spatial heterogeneity. If the environment changes in time or if it is unstable relative to the life span of the organisms, each individual will have to face diverse environments appearing one after the other. A series of genotypes, each well adapted to one or another of the conditions that prevail at various times, will not succeed very well, because each organism will fare well at one period of its life but not at others. A better strategy is to have a population with one or a few genotypes that survive well in all the successive environments.

If the environment changes from place to place, the situation is likely to be different. Although a single genotype, well adapted to the various environmental patches, is a possible strategy, a variety of genotypes, with some individuals optimally adapted to each subenvironment, might fare still better. The ability of the population to exploit the environmental patchiness is thereby increased. Diversifying selection refers to the situation in which natural selection favours different genotypes in different subenvironments.

The efficiency of diversifying natural selection is quite apparent in circumstances in which populations living a short distance apart have become genetically differentiated. In one example, populations of bent grass can be found growing on heaps of mining refuse heavily contaminated with metals such as lead and copper. The soil has become so contaminated that it is toxic to most plants, but the dense



Figure 8: Industrial melanism in the peppered moth, *Biston betularia*. A typical light-gray moth and a darkly pigmented variant rest on two oak trees. On the lichen-covered trunk (left), the light-gray moth is inconspicuous; it is quite conspicuous on the soot-covered tree (right).
From the experiments of Dr. H.B.D. Kettlewell, University of Oxford; photographs by John S. Haywood

stands of bent grass growing over these refuse heaps have been shown to possess genes that make them resistant to high concentrations of lead and copper. But only a few metres from the contaminated soil can be found bent grass plants that are not resistant to these metals. Bent grasses reproduce primarily by cross-pollination, so that the resistant grass receives wind-borne pollen from the neighbouring nonresistant plants. Yet they maintain their genetic differentiation because nonresistant seedlings are unable to grow in the contaminated soil and, in nearby uncontaminated soil, the nonresistant seedlings outgrow the resistant ones. The evolution of these resistant strains has taken place in the fewer than 400 years since the mines were first opened.

Protective morphologies and protective coloration exist in many animals as a defense against predators or as a cover against prey. Sometimes an organism mimics the appearance of a different one for protection. Diversifying selection often occurs in association with mimicry. A species of swallowtail butterfly, *Papilio dardanus*, is endemic in tropical and Southern Africa. Males have yellow and black wings, with characteristic tails in the second pair of wings. But females in many localities are conspicuously different from males; their wings lack tails and have colour patterns that vary from place to place. The explanation for these differences stems from the fact that *P. dardanus* can be eaten safely by birds. Many other butterfly species are noxious to birds, and so they are carefully avoided as food. In localities where *P. dardanus* coexists with noxious butterfly species, the *P. dardanus* females have evolved an appearance that mimics the noxious species. Birds confuse the mimics with their models and do not prey on them. In different localities the females mimic different species; in some areas two or even three different female forms exist, each mimicking different noxious species. Diversifying selection has resulted in different phenotypes of *P. dardanus* as a protection from bird predators.

Mimicry

Sexual selection. Mutual attraction between the sexes is an important factor in reproduction. The males and females of many animal species are similar in size and shape except for the sexual organs and secondary sexual characteristics such as the breasts of female mammals. There are, however, species in which the sexes exhibit striking dimorphism. Particularly in birds and mammals, the males are often larger and stronger, more brightly coloured, or endowed with conspicuous adornments. But bright colours make animals more visible to predators—the long plumage of male peacocks and birds of paradise and the enormous antlers of aged male deer are cumbersome loads in the best of cases. Darwin knew that natural selection could not be expected to favour the evolution of disadvantageous traits, and he was able to offer a solution to this problem. He proposed that such traits arise by "sexual selection," which "depends not on a struggle for existence in relation to other organic beings or to external conditions but on a struggle between the individuals of one sex, generally the males, for the possession of the other sex."

The concept of sexual selection as a special form of natural selection is easily explained. Other things being equal, organisms more proficient in securing mates have higher fitness. There are two general circumstances leading to sexual selection. One is the preference shown by one sex (often the females) for individuals of the other sex that exhibit certain traits. The other is increased strength (usually among the males) that yields greater success in securing mates.

Selection by females for male traits

The presence of a particular trait among the members of one sex can make them somehow more attractive to the opposite sex. This type of "sex appeal" has been experimentally demonstrated in all sorts of animals, from vinegar flies to pigeons, mice, dogs, and rhesus monkeys. When, for example, *Drosophila* flies, some with yellow bodies as a result of spontaneous mutation and others with the normal yellowish gray pigmentation, are placed together, normal males are preferred over yellow males by females with either body colour.

Sexual selection can also come about because a trait—the antlers of a stag, for example—increases prowess in competition with members of the same sex. Stags, rams, and bulls use antlers or horns in contests of strength; a winning male usually secures more female mates. Therefore, sexual selection may lead to increased size and aggressiveness in males. Male baboons are more than twice as large as females, and the behaviour of the docile females contrasts with that of the aggressive males. A similar dimorphism occurs in the northern sea lion, *Eumetopias jubata*, where males weigh about 1,000 kg (2,200 pounds), about three times as much as females. The males fight fiercely in their competition for females; large, battle-scarred males occupy their own rocky islets, each holding a harem of as many as 20 females. Among many mammals that live in packs, troops, or herds—such as wolves, horses, and buffaloes—there usually is a hierarchy of dominance based on age and strength, with males that rank high in the hierarchy doing most of the mating.

Kin selection and reciprocal altruism. The apparent altruistic behaviour of many animals is, like some manifestations of sexual selection, a trait that at first seems incompatible with the theory of natural selection. Altruism is a form of behaviour that benefits other individuals at the expense of the one that performs the action; the fitness of the altruist is diminished by its behaviour, whereas individuals that act selfishly benefit from it at no cost to themselves. Accordingly, it might be expected that natural selection would foster the development of selfish behaviour and eliminate altruism. This conclusion is not so compelling when it is noticed that the beneficiaries of altruistic behaviour are usually relatives. They all carry the same genes, including the genes that promote altruistic behaviour. Altruism may evolve by kin selection, which is simply a type of natural selection in which relatives are taken into consideration when evaluating an individual's fitness.

Altruism

Natural selection favours genes that increase the reproductive success of their carriers, but it is not necessary that all individuals that share a given genotype have higher reproductive success. It suffices that carriers of the genotype reproduce more successfully on the average than those possessing alternative genotypes. A parent shares half of its genes with each progeny, so a gene that promotes parental altruism is favoured by selection if the behaviour's cost to the parent is less than half of its average benefits to the progeny. Such a gene will be more likely to increase in frequency through the generations than an alternative gene that does not promote altruistic behaviour. Parental care is, therefore, a form of altruism readily explained by kin selection. The parent spends some energy caring for the progeny because it increases the reproductive success of the parent's genes.

Kin selection extends beyond the relationship between parents and their offspring. It facilitates the development of altruistic behaviour when the energy invested, or the risk incurred, by an individual is compensated in excess by the benefits ensuing to relatives. The closer the relationship between the beneficiaries and the altruist and the greater the number of beneficiaries, the higher the risks and efforts warranted in the altruist. Individuals that live together in a herd or troop usually are related and often behave toward each other in this way. Adult zebras, for instance, will turn toward an attacking predator to protect the young in the herd rather than fleeing to protect themselves.

Altruism also occurs among unrelated individuals when the behaviour is reciprocal and the altruist's costs are smaller than the benefits to the recipient. This reciprocal altruism is found in the mutual grooming of chimpanzees and other primates as they clean each other of lice and other pests. Another example appears in flocks of birds that post sentinels to warn of danger. A crow sitting in a tree watching for predators while the rest of the flock forages incurs a small loss by not feeding, but this loss is well compensated by the protection it receives when it itself forages and others of the flock stand guard.

Evolution of social insects

A particularly valuable contribution of the theory of kin selection is its explanation of the evolution of social behaviour among ants, bees, wasps, and other social insects. In honeybee populations, for example, the female workers build the hive, care for the young, and gather food, but they are sterile; the queen bee alone produces progeny. It would seem that the workers' behaviour would in no way be promoted or maintained by natural selection. Any

genes causing such behaviour would seem likely to be eliminated from the population, because individuals exhibiting the behaviour increase not their own reproductive success but that of the queen. The situation is, however, more complex.

Queen bees produce some eggs that remain unfertilized and develop into males, or drones, having a mother but no father. Their main role is to engage in the nuptial flight during which one of them fertilizes a new queen. Other eggs laid by queen bees are fertilized and develop into females, the large majority of which are workers. A queen typically mates with a single male once during her lifetime; the male's sperm is stored in the queen's spermatheca, from which it is gradually released as she lays fertilized eggs. All the queen's female progeny therefore have the same father, so that workers are more closely related to one another and to any new sister queen than they are to the mother queen. The female workers receive one-half of their genes from the mother and one-half from the father, but they share among themselves three-quarters of their genes. The half of the set from the father is the same in every worker, because the father had only one set of genes rather than two to pass on (the male developed from an unfertilized egg, so all his sperm carry the same set of genes). The other half of the workers' genes come from the mother, and on the average half of them are identical in any two sisters. Consequently, with three-quarters of her genes present in her sisters but only half of her genes able to be passed on to a daughter, a worker's genes are transmitted one and a half times more effectively when she raises a sister (whether another worker or a new queen) than if she produces a daughter of her own.

Species and speciation

THE CONCEPT OF SPECIES

Darwin sought to explain the splendid multiformity of the living world—thousands of organisms of the most diverse kinds, from lowly worms to spectacular birds of paradise, from yeasts and molds to oaks and orchids. His *On the Origin of Species by Means of Natural Selection* (1859) is a sustained argument showing that the diversity of organisms and their characteristics can be explained as the result of natural processes.

Species come about as the result of gradual change prompted by natural selection. Environments are continuously changing in time, and they differ from place to place. Natural selection therefore favours different characteristics in different situations. The accumulation of differences eventually yields different species.

Everyday experience teaches that there are different kinds of organisms and also teaches how to identify them. Everyone knows that people belong to the human species and are different from cats and dogs, which in turn are different from each other. There are differences between people, as well as between cats and dogs, but individuals of the same species are considerably more similar among themselves than they are to individuals of other species.

External similarity is the common basis for identifying individuals as being members of the same species. Nevertheless, there is more to a species than outward appearance. A bulldog, a terrier, and a golden retriever are very different in appearance, but they are all dogs because they can interbreed. People can also interbreed with one another, and so can cats with other cats, but people cannot interbreed with dogs or cats, nor can these with each other. It is clear then that although species are usually identified by appearance, there is something basic, of great biological significance, behind similarity of appearance—individuals of a species are able to interbreed with one another but not with members of other species. This is expressed in the following definition: Species are groups of interbreeding natural populations that are reproductively isolated from other such groups. (For an explanation and discussion of this concept, see below *Reproductive isolation*.)

Biological underpinnings of the species concept

The ability to interbreed is of great evolutionary importance, because it determines that species are independent evolutionary units. Genetic changes originate in single individuals; they can spread by natural selection to all members of the species but not to individuals of other species. Individuals of a species share a common gene pool that is not shared by individuals of other species. Different species have independently evolving gene pools because they are reproductively isolated.

Although the criterion for deciding whether individuals belong to the same species is clear, there may be ambiguity in practice for two reasons. One is lack of knowledge—it may not be known for certain whether individuals living in different sites belong to the same species, because it is not known whether they can naturally interbreed. The other reason for ambiguity is rooted in the nature of evolution as a gradual process. Two geographically separate populations that at one time were members of the same species later may have diverged into two different species. Since the process is gradual, there is no particular point at which it is possible to say that the two populations have become two different species.

Distinguishing species in organisms separated in time

A related situation pertains to organisms living at different times. There is no way to test if today's humans could interbreed with those who lived thousands of years ago. It seems reasonable that living people, or living cats, would be able to interbreed with people, or cats, exactly like those that lived a few generations earlier. But what about ancestors removed by a thousand or a million generations? The ancestors of modern humans that lived 500,000 years ago (about 20,000 generations) are classified as the species *Homo erectus*. There is no exact time at which *H. erectus* became *H. sapiens*, but it would not be appropriate to classify remote human ancestors and modern humans in the same species just because the changes from one generation to the next were small. It is useful to distinguish between the two groups by means of different species names, just as it is useful to give different names to childhood and adulthood even though no single moment can separate one from the other. Biologists distinguish species in organisms that lived at different times by means of a commonsense morphological criterion: If two organisms differ from each other in form and structure about as much as do two living individuals belonging to two different species, they are classified in separate species and given different names.

The definition of species given above applies only to organisms able to interbreed. Bacteria and cyanobacteria (blue-green algae), for example, reproduce not sexually but by fission. Organisms that lack sexual reproduction are classified into different species according to criteria such as external morphology, chemical and physiological properties, and genetic constitution.

THE ORIGIN OF SPECIES

Reproductive isolation. Among sexual organisms, individuals that are able to interbreed belong to the same species. The biological properties of organisms that prevent interbreeding are called reproductive isolating mechanisms (RIMs). Oaks on different islands, minnows in different rivers, or squirrels in different mountain ranges cannot interbreed because they are physically separated, not necessarily because they are biologically incompatible. Geographic separation, therefore, is not a RIM.

Reproductive isolating mechanisms

There are two general categories of reproductive isolating mechanisms: prezygotic, or those that take effect before fertilization, and postzygotic, those that take effect afterward. Prezygotic RIMs prevent the formation of hybrids between members of different populations through ecological, temporal, ethological (behavioral), mechanical, and gametic isolation. Postzygotic RIMs reduce the viability or fertility of hybrids or their progeny.

Ecological isolation. Populations may occupy the same territory but live in different habitats and so not meet. The *Anopheles maculipennis* group consists of six mosquito species, some of which are involved in the transmission of malaria. Although the species are virtually indistinguishable morphologically, they are isolated reproductively, in part because they breed in different habitats. Some breed in brackish water, others in running fresh water, and still others in stagnant fresh water.

Temporal isolation. Populations may mate or flower at different seasons or different times of day. Three tropical orchid species of the genus *Dendrobium* each flower for a

single day; the flowers open at dawn and wither by nightfall. Flowering occurs in response to certain meteorological stimuli, such as a sudden storm on a hot day. The same stimulus acts on all three species, but the lapse between the stimulus and flowering is 8 days in one species, 9 in another, and 10 or 11 in the third. Interspecific fertilization is impossible because, at the time the flowers of one species open, those of the other species have already withered or have not yet matured.

A peculiar form of temporal isolation exists between pairs of closely related species of cicadas, in which one species of each pair emerges every 13 years, the other every 17 years. The two species of a pair may be sympatric (live in the same territory), but they have an opportunity to form hybrids only once every 221 (or 13×17) years.

Ethological (behavioral) isolation. Sexual attraction between males and females of a given species may be weak or absent. In most animal species, members of the two sexes must first search for each other and come together. Species-specific courtship rituals

Complex courtship rituals then take place, with the male often taking the initiative and the female responding. This in turn generates additional actions by the male and responses by the female, and eventually there is copulation, or sexual intercourse (or, in the case of some aquatic organisms, release of the sex cells for fertilization in the water). These elaborate rituals are specific to a species and play a significant part in species recognition. If the sequence of events in the search-courting-mating process is rendered disharmonious by either of the two sexes, then the entire process will be interrupted. Courtship and mating rituals have been extensively analyzed in some mammals, birds, and fishes and in a number of insect species.

Ethological isolation is often the most potent RIM to keep animal species from interbreeding. It can be remarkably strong even among closely related species. The vinegar flies *Drosophila serrata*, *D. birchii*, and *D. dominicana* are three sibling species (that is, species nearly indistinguishable morphologically) that are endemic in Australia and on the islands of New Guinea and New Britain. In many areas these three species occupy the same territory, but no hybrids are known to occur in nature. The strength of their ethological isolation has been tested in the laboratory by placing together groups of females and males in various combinations for several days. When the flies were all of the same species but the female and male groups each came from different geographic origins, a large majority of the females (usually 90 percent or more) were fertilized. But no inseminations or very few (less than 4 percent) took place when males and females were of different species, whether from the same or different geographic origins.

It should be added that the rare interspecific inseminations that did occur among the vinegar flies produced hybrid adult individuals in very few instances, and the hybrids were always sterile. This illustrates a common pattern—reproductive isolation between species is maintained by several RIMs in succession; if one breaks down, others are still present. In addition to ethological isolation, failure of the hybrids to survive and hybrid sterility (see below *Hybrid inviability* and *Hybrid sterility*) prevent successful breeding between members of the three *Drosophila* species and between many other animal species as well.

Species recognition during courtship involves stimuli that may be chemical (olfactory), visual, auditory, or tactile. Pheromones in species recognition

Pheromones are specific substances that play a critical role in recognition between members of a species; they have been chemically identified in such insects as ants, moths, butterflies, and beetles and in such vertebrates as fish, reptiles, and mammals. The "songs" of birds, frogs, and insects (the last of which produce these sounds by vibrating or rubbing their wings) are species recognition signals. Some form of physical contact or touching occurs in many mammals but also in *Drosophila* flies and other insects.

Mechanical isolation. Copulation is often impossible between different animal species because of the incompatible shape and size of the genitalia; in plants, variations in flower structure may impede pollination. In two species of sage from California, for example, the two-lipped flowers of *Salvia mellifera* have stamens and style (respectively, the male structure that produces the pollen and the female structure that bears the pollen-receptive surface, the stigma) in the upper lip, whereas *S. apiana* has long stamens and style and a specialized floral configuration. *S. mellifera* is pollinated by small or medium-sized bees that carry pollen on their backs from flower to flower. *S. apiana*, however, is pollinated by large carpenter bees and bumblebees that carry the pollen on their wings and other body parts. Even if the pollinators of one species visit flowers of the other, pollination cannot occur because the pollen does not come into contact with the style of the alternative species.

Gametic isolation. Marine animals often discharge their eggs and sperm into the surrounding water, where fertilization takes place. Gametes of different species may fail to attract one another. For example, the sea urchins *Strongylocentrotus purpuratus* and *S. franciscanus* can be induced to release their eggs and sperm simultaneously, but most of the fertilizations that result are between eggs and sperm of the same species. In animals with internal fertilization, sperm cells may be unable to function in the sexual ducts of females of different species. In plants, pollen grains of one species typically fail to germinate on the stigma of another species, so that the pollen tubes never reach the ovary where fertilization would occur. Impediments to interspecific fertilization

Hybrid inviability. Occasionally, prezygotic mechanisms are absent or break down so that interspecific zygotes (fertilized eggs) are formed. These zygotes, however, often fail to develop into mature individuals. The hybrid embryos of sheep and goats, for example, die in the early developmental stages before birth. Hybrid inviability is common in plants, whose hybrid seeds often fail to germinate or die shortly after germination.

Hybrid sterility. Hybrid zygotes sometimes develop into adults, such as mules (hybrids between female horses and male donkeys), but the adults fail to develop functional gametes and are sterile.

Hybrid breakdown. In plants more than in animals, hybrids between closely related species are sometimes partially fertile. Gene exchange may nevertheless be inhibited because the offspring are poorly viable or sterile. Hybrids between the cotton species *Gossypium barbadense*, *G. hirsutum*, and *G. tomentosum* appear vigorous and fertile, but their progenies die in seed or early in development, or they develop into sparse, weak plants.

A model of speciation. Since species are groups of populations reproductively isolated from one another, asking about the origin of species is equivalent to asking how reproductive isolation arises between populations. Two theories have been advanced to answer this question. One theory considers isolation as an accidental by-product of genetic divergence. Populations that become genetically less and less alike (as a consequence, for example, of adaptation to different environments) may eventually be unable to interbreed because their gene pools are disharmonious. The other theory regards isolation as a product of natural selection. Whenever hybrid individuals are less fit than nonhybrids, natural selection will directly promote the development of RIMs. This occurs because genetic variants interfering with hybridization have greater fitness than those favouring hybridization, given that the latter are often present in hybrids with poor fitness. Two theoretical mechanisms

These two theories of the origin of reproductive isolation are not mutually exclusive. Reproductive isolation may indeed come about incidental to genetic divergence between separated populations. Consider, for example, the evolution of many endemic species of plants and animals in the Hawaiian archipelago. The ancestors of these species arrived on these islands several million years ago. There they evolved as they became adapted to the environmental conditions and colonizing opportunities present. Reproductive isolation between the populations evolving in Hawaii and the populations on continents was never directly promoted by natural selection because their geographic remoteness forestalled any opportunities for hybridizing. Nevertheless, reproductive isolation became complete in many cases as a result of gradual genetic divergence over thousands of generations.

Frequently, however, the course of speciation involves the processes postulated by both theories—reproductive isola-

tion starts as a by-product of gradual evolutionary divergence but is completed by natural selection directly promoting the evolution of prezygotic RIMs.

The separate sets of processes identified by the two speciation theories may be seen, therefore, as different stages in the splitting of an evolutionary lineage into two species. The splitting starts when gene flow is somehow interrupted between two populations. It is necessary that gene flow be interrupted, because otherwise the two groups of individuals would still share in a common gene pool and fail to become genetically different. Interruption may be due to geographic separation, or it may be initiated by some genetic change that affects some individuals of the species but not others living in the same territory. The two genetically isolated groups are likely to become more and more different as time goes on. Eventually, some incipient reproductive isolation may take effect because the two gene pools are no longer adapting in concert. Hybrid individuals, which carry genes combined from the two gene pools, will therefore experience reduced viability or fertility.

The circumstances just described may persist for so long that the populations become completely differentiated into separate species. It happens quite commonly, however, in both animals and plants that opportunities for hybridization arise between two populations that are becoming genetically differentiated. Two outcomes are possible. One is that the hybrids manifest little or no reduction of fitness, so that gene exchange between the two populations proceeds freely, eventually leading to their integration into a single gene pool. The second possible outcome is that reduction of fitness in the hybrids is sufficiently large for natural selection to favour the emergence of prezygotic RIMs preventing the formation of hybrids altogether. This situation may be identified as the second stage in the speciation process.

Evolution of prezygotic RIMs

How natural selection brings about the evolution of prezygotic RIMs can be understood in the following way. Beginning with two populations, P1 and P2, assume that there are gene variants in P1 that increase the probability that P1 individuals will choose P1 rather than P2 mates. Such gene variants will increase in frequency in the P1 population, because they are more often present in the progenies of P1×P1 matings, which have normal fitness. The alternative genetic variants that do not favour P1×P1 matings will be more often present in the progenies of P1×P2 matings, which have lower fitness. The same process will enhance the frequency in the P2 population of genetic variants that lead P2 individuals to choose P2 rather than P1 mates. Prezygotic RIMs may therefore evolve in both populations and lead to their becoming two separate species.

The two stages of the process of speciation can be characterized, finally, by outlining their distinctions. The first stage primarily involves the appearance of postzygotic RIMs as accidental by-products of overall genetic differentiation rather than as express targets of natural selection. The second stage involves the evolution of prezygotic RIMs that are directly promoted by natural selection. The first stage may come about suddenly, in one or a few generations, rather than as a long, gradual process. The second stage follows the first in time but need not always be present.

Geographic speciation. One common mode of speciation is known as geographic, or allopatric (in separate territories), speciation. The general model of the speciation process advanced in the previous section applies well to geographic speciation. The first stage begins as a result of geographic separation between populations. This may occur when a few colonizers reach a geographically separate habitat, perhaps an island, lake, river, isolated valley, or mountain range. Alternately, a population may be split into two geographically separate ones by topographic changes, such as the disappearance of a water connection between two lakes, or by an invasion of competitors, parasites, or predators into the intermediate zone. If these types of separation continue for some time, postzygotic RIMs may appear as a result of gradual genetic divergence.

In the second stage, an opportunity for interbreeding may later be brought about by topographic changes reestablishing continuity between the previously isolated territories or by ecological changes once again making the intermediate territory habitable for the organisms. If postzygotic RIMs that evolved during the separation sufficiently reduce the fitness of hybrids of the two populations, natural selection will foster the development of prezygotic RIMs, and the two populations may go on to evolve into two species despite their occupying the same geographic territory.

Investigation has been made of many populations that are in the first stage of geographic speciation. There are fewer well-documented instances of the second stage, presumably because this occurs fairly rapidly in evolutionary time.

Two stages in vinegar fly speciation

Both stages of speciation are present in a group of six closely related species of New World *Drosophila* flies that have been extensively studied by evolutionists for several decades. Two of these sibling species, *D. willistoni* and *D. equinoxialis*, each consist of groups of populations in the first stage of speciation and are identified as different subspecies. Two *D. willistoni* subspecies live in continental South America—*D. willistoni quechua* lives west of the Andes and *D. willistoni willistoni* east of the Andes. They are effectively separated by the Andes because the flies cannot live at high altitudes. It is not known whether their geographic separation is as old as the Andes, but it has existed long enough for postzygotic RIMs to have evolved. When the two subspecies are crossed in the laboratory, the hybrid males are completely sterile if the mother came from the *quechua* subspecies, but in the reciprocal cross all hybrids are fertile. If hybridization should occur in nature, selection would favour the evolution of prezygotic RIMs because of the complete sterility of half of the hybrid males.

Another pair of subspecies consists of *D. equinoxialis equinoxialis*, which inhabits continental South America, and *D. equinoxialis caribbensis*, which lives in Central America and the Caribbean. Crosses made in the laboratory between these two subspecies always produce sterile males, irrespective of the subspecies of the mother. Natural selection would, then, promote prezygotic RIMs between these two subspecies more strongly than between those of *D. willistoni*. But, in accord with the speciation model presented above, laboratory experiments show no evidence of the development of ethological isolation or of any other prezygotic RIM, presumably because the geographic isolation of the subspecies has forestalled hybridization between members.

One more sibling species of the group is *D. paulistorum*, a species that includes groups of populations well into the second stage of geographic speciation. Six such groups have been identified as semispecies, or incipient species, two or three of which are sympatric in many localities. Male hybrids between individuals of the different semispecies are sterile; laboratory crosses always yield fertile females but sterile males.

Ethological isolation in incipient species

Whenever two or three incipient species of *D. paulistorum* have come into contact in nature, the second stage of speciation has led to the development of ethological isolation, which ranges from incipient to virtually complete. Laboratory experiments show that when both incipient species are from the same locality, their ethological isolation is complete—only individuals of the same incipient species mate. When the individuals from different incipient species come from different localities, however, ethological isolation is usually present but far from complete. This is precisely as the speciation model predicts. Natural selection effectively promotes ethological isolation in territories where two incipient species live together, but the genes responsible for this isolation have not yet fully spread to populations in which one of the two incipient species is not present.

The eventual outcome of the process of geographic speciation is complete reproductive isolation, as can be observed among the species of the New World *Drosophila* group under discussion. *D. willistoni*, *D. equinoxialis*, *D. tropicalis*, and *D. paulistorum* coexist sympatrically over wide regions of Central and South America while preserving their separate gene pools. Hybrids are not known in nature and are almost impossible to obtain in the laboratory; moreover, all interspecific hybrid males at least are completely sterile. This total reproductive isolation has evolved, however, with very little morphological differenti-

ation. Females from different sibling species cannot be distinguished by experts, while males can be identified only by small differences in the shape of their genitalia, unrecognizable except under a microscope.

Adaptive radiation. The geographic separation of populations derived from common ancestors may continue long enough so that the populations become completely differentiated species before ever regaining sympatry and the opportunity to interbreed. As the allopatric populations continue evolving independently, RIMs develop and morphological differences may arise. The second stage of speciation—in which natural selection directly stimulates the evolution of RIMs—never comes about in such situations, because reproductive isolation takes place simply as a consequence of the continued separate evolution of the populations.

This form of allopatric speciation is particularly apparent when colonizers reach geographically remote areas, such as islands, where they find few or no competitors and have an opportunity to diverge as they become adapted to the new environment. Sometimes the new regions offer a multiplicity of environments to the colonizers, giving rise to several different lineages and species. This process of rapid divergence of multiple species from a single ancestral lineage is called adaptive radiation.

Galapagos finches

Many examples of speciation by adaptive radiation are found in archipelagoes removed from the mainland. The Galapagos Islands are about 1,000 kilometres (600 miles) off the west coast of South America. When Charles Darwin arrived there in 1835 during his voyage on the HMS *Beagle*, he discovered many species not found anywhere else in the world—for example, several species of finch, of which 14 are now known to exist (called Galapagos, or Darwin's, finches). These passerine birds have adapted to a diversity of habitats and diets, some feeding mostly on plants, others exclusively on insects. The various shapes of their bills are clearly adapted to probing, grasping, biting, or crushing—the diverse ways in which the different Galapagos species obtain their food (Figure 9). The explanation for such diversity is that the ancestor of Galapagos finches arrived in the islands before other kinds of birds and encountered an abundance of unoccupied ecological niches. Its descendants underwent adaptive radiation, evolving a variety of finch species with ways of life capable of exploiting opportunities that on various continents are already exploited by other species.

The Hawaiian archipelago also provides striking examples of adaptive radiation. Its several volcanic islands, ranging from 1 million to more than 10 million years in age, are far from any continent or even other large islands. In their relatively small total land area, an astounding number of plant and animal species exist. Most have evolved on the islands, among them about two dozen species (one-third of them now extinct) of honeycreepers, birds of the family Drepanididae, all derived from a single immigrant form. In fact, all but one of Hawaii's 71 native bird species are endemic; that is, they have evolved there and are found nowhere else. More than 90 percent of the native species of flowering plants, land mollusks, and insects are also endemic, as are two-thirds of the 168 species of ferns.

There are more than 500 native Hawaiian species of *Drosophila* flies—about one-third of the world's total number of known species. Far greater morphological and ecological diversity exists among the species in Hawaii than anywhere else in the world. The species of *Drosophila* in Hawaii have diverged by adaptive radiation from one or a few colonizers, which encountered an assortment of ecological niches that in other lands were occupied by different groups of flies or insects but that were available for exploitation in these remote islands.

Quantum speciation. In some modes of speciation the first stage is achieved in a short period of time. These modes are known by a variety of names, such as *quantum*, *rapid*, and *saltational* speciation, all suggesting the shortening of time involved. They are also known as *sympatric* speciation, alluding to the fact that quantum speciation often leads to speciation between populations that exist in the same territory or habitat. An important form of quantum speciation, polyploidy, is discussed separately below.

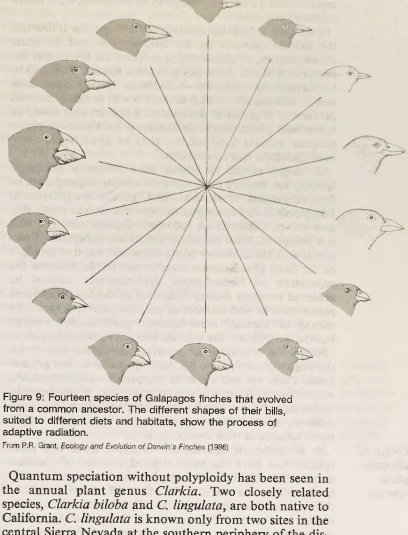

Figure 9: Fourteen species of Galapagos finches that evolved from a common ancestor. The different shapes of their bills, suited to different diets and habitats, show the process of adaptive radiation.
From P.R. Grant, *Ecology and Evolution of Darwin's Finches* (1986)

Quantum speciation without polyploidy has been seen in the annual plant genus *Clarkia*. Two closely related species, *Clarkia biloba* and *C. lingulata*, are both native to California. *C. lingulata* is known only from two sites in the central Sierra Nevada at the southern periphery of the distribution of *C. biloba*, from which it evolved starting with translocations and other chromosomal mutations (see above the section *Chromosomal mutations*). Such chromosomal rearrangements arise suddenly but reduce the fertility of heterozygous individuals. *Clarkia* species are capable of self-fertilization, which facilitates the propagation of the chromosomal mutants in different sets of individuals even within a single locality. This makes hybridization possible with nonmutant individuals and allows the second stage of speciation to go ahead.

Chromosomal mutations as starting points

Chromosomal mutations are often the starting point of quantum speciation in animals, particularly in groups such as moles and other rodents that live underground or have little mobility. Mole rats of the species group *Spalax ehrenbergi* in Israel and gophers of the species group *Thomomys talpoides* in the northern Rocky Mountains are well-studied examples.

The speciation process may also be initiated by changes in just one or a few gene loci when these alterations result in a change of ecological niche or, in the case of parasites, a change of host. Many parasites use their host as a place for courtship and mating, so organisms with two different host preferences may become reproductively isolated. If the hybrids show poor fitness because they are not effective parasites in either of the two hosts, natural selection will favour the development of additional RIMs. This type of speciation seems to be common among parasitic insects, a large group comprising tens of thousands of species.

Polyploidy. As is discussed above in *The process of evolution: Evolution as a genetic function: The origin of genetic variation: mutations: Chromosomal mutations*, the multiplication of entire sets of chromosomes is known as polyploidy. Whereas a diploid organism carries in the nucleus of each cell two sets of chromosomes, one inherited from each parent, a polyploid organism has three or more sets of chromosomes. Many cultivated plants are polyploid—bananas are triploid, potatoes are tetraploid, bread wheat is hexaploid, some strawberries are octaploid. These cultivated polyploids do not exist in nature, at least in any

significant frequency. Some of them first appeared spontaneously; others, such as octaploid strawberries, were intentionally produced.

In animals polyploidy is relatively rare because it disrupts the balance between the sex chromosome and the other chromosomes, a balance being required for the proper development of sex. Naturally polyploid species are found in hermaphroditic animals—individuals having both male and female organs—which include snails, earthworms, and planarians (a group of flatworms). They are also found in forms with parthenogenetic females (which produce viable progeny without fertilization), such as some beetles, sow bugs, goldfish, and salamanders.

All major groups of plants have naturally polyploid species, but they are most common among angiosperms, or flowering plants, of which about 47 percent are polyploids. Polyploidy is rare among gymnosperms, such as pines, firs, and cedars, although the redwood, *Sequoia sempervirens*, is a polyploid. Most polyploid plants are tetraploids. Polyploids with three, five, or some other odd-number multiple of the basic chromosome number are sterile, because the separation of homologous chromosomes cannot be achieved properly during formation of the sex cells. Some plants with an odd number of chromosome sets persist by means of asexual reproduction, particularly through human cultivation; the triploid banana is one example.

Polyploidy is a mode of quantum speciation that yields the beginnings of a new species in just one or two generations. There are two kinds of polyploids—autopolyploids, which derive from a single species, and allopolyploids, which stem from a combination of chromosome sets from different species. Allopolyploid plant species are much more numerous than autopolyploids.

Origin of allopolyploid species

An allopolyploid species can originate from two plant species that have the same diploid number of chromosomes. The chromosome complement of one species may be symbolized as *AA*, and the other *BB*. A hybrid of two different species, represented as *AB*, will usually be sterile owing to abnormal chromosome pairing and segregation during formation at meiosis of the gametes, which are haploid (*i.e.*, having only half of the chromosomes, of which in a given gamete some come from the *A* set and some from the *B* set). But chromosome doubling may occur in a diploid cell as a consequence of abnormal mitosis, in which the chromosomes divide but the cell does not. If this happens in the hybrid above, *AB*, the result is a plant cell with four sets of chromosomes, *AABB*. Such a tetraploid cell may proliferate within the plant (which is otherwise constituted of diploid cells) and produce branches and flowers of tetraploid cells. Because the flowers' cells carry two chromosomes of each kind, they can produce functional diploid gametes via meiosis with the constitution *AB*. The union of two such gametes, such as happens during self-fertilization, produces a complete tetraploid individual (*AABB*). In this way, self-fertilization in plants makes possible the formation of a tetraploid individual as the result of a single abnormal cell division.

Autopolyploids originate similarly, but the individual in which the abnormal mitosis occurs is not a hybrid. Self-fertilization thus enables a single individual to multiply and give rise to a population. This population is a new species, since polyploid individuals are reproductively isolated from their diploid ancestors. A cross between a tetraploid and a diploid yields triploid progeny, which are sterile.

GENETIC DIFFERENTIATION DURING SPECIATION

Genetic changes underlie all evolutionary processes. In order to understand speciation and its role in evolution, it is useful to know how much genetic change takes place during the course of species development. It is of considerable significance to ascertain whether new species arise by altering only a few genes or whether the process requires drastic changes—a genetic "revolution," as postulated by some evolutionists in the past. The issue is best considered separately with respect to each of the two stages of speciation and to the various modes of speciation.

The question of how much genetic differentiation occurs during speciation has become answerable only with the relatively recent development of appropriate methods for comparing genes of different species. Genetic change is measured with two parameters—genetic identity (*I*), which estimates the proportion of genes that are identical in two populations, and genetic distance (*D*), which estimates the proportion of gene changes that have occurred in the separate evolution of two populations. The value of *I* may range between 0 and 1, which correspond to the extreme situations in which no or all genes are identical, respectively; the value of *D* may range from zero to infinity. *D* can reach beyond 1 because each gene may change more than once in one or both populations as evolution goes on for many generations.

Measurement of genetic change

As a model of geographic speciation, the *Drosophila willistoni* group of flies offers the distinct advantage of exhibiting both stages of the speciation process. The *D. willistoni* group consists of several closely related species, some of which in turn consist of several incipient species, subspecies, or both. About 30 randomly selected genes have been studied in a large number of natural populations of these species. The results are summarized in Table 3. The most significant figures are those given in lines 2 and 3 of the table, which represent the first and second stages, respectively, of the process of geographic speciation. The 0.230 value for *D* (line 2) means that about 23 gene changes have occurred for every 100 gene loci in the separate evolution of two subspecies—that is, the sum of the changes that have occurred in the two separately evolving lineages is 23 percent of all the genes. These are populations well advanced in the first stage of speciation, as manifested by the sterility of the hybrid males.

Table 3: Genetic Differentiation Between Populations of *Drosophila willistoni*

level of comparison	*I* (genetic identity)	*D* (genetic distance)
1. Local populations	0.970±0.006	0.031±0.007
2. Subspecies	0.795±0.013	0.230±0.016
3. Incipient species	0.798±0.026	0.226±0.033
4. Sibling species	0.563±0.023	0.581±0.039
5. Morphologically different species	0.352±0.023	1.056±0.068

The genetic distance between incipient species (Table 3, line 3) is the same, within experimental error, as that between the subspecies, or 22.6 percent. This implies that the development of ethological isolation, as it is found in these populations, does not require many genetic changes beyond those that occurred during the first stage of speciation. Indeed, no additional gene changes were detected in these experiments. The absence of major genetic changes during the second stage of speciation can be understood by considering the role of natural selection, which directly promotes the evolution of prezygotic RIMs during the second stage, so that only genes modifying mate choice need to change. In contrast, the development of postzygotic RIMs during the first stage occurs only after there is substantial genetic differentiation between populations, because it comes about only as an incidental outcome of overall genetic divergence.

Sibling species, such as *D. willistoni* and *D. equinoxialis*, exhibit 58 gene changes for every 100 gene loci after their divergence from a common ancestor (Table 3, line 4). It is noteworthy that this much genetic evolution has occurred without altering the external morphology of these organisms. In the evolution of morphologically different species (line 5), the number of gene changes is greater yet, as would be expected.

Genetic changes concomitant with one or the other of the two stages in the speciation process have been studied in a number of organisms, from insects and other invertebrates to all sorts of vertebrates, including mammals. The amount of genetic change during geographic speciation varies between organisms, but the two main observations made in the *D. willistoni* group seem to apply quite generally. These are that the evolution of postzygotic mechanisms during the first stage is accompanied by substantial genetic change (a majority of values for genetic distance, *D*, range between 0.15 and 0.30) and that relatively few additional genetic changes are required during the second stage.

Genetic change in quantum speciation

The conclusions drawn from the investigation of geographic speciation make it possible to predict the relative amounts of genetic change expected in the quantum modes of speciation. Polyploid species are a special case—they arise suddenly in one or a few generations, and at first they are not expected to be genetically different from their ancestors. More generally, quantum speciation involves a shortening of the first stage of speciation, so that postzygotic RIMs arise directly as a consequence of specific genetic changes (such as chromosome mutations). Populations in the first stage of quantum speciation, therefore, need not be substantially different in individual gene loci. This has been confirmed by genetic investigations of species recently arisen by quantum speciation. For example, the average genetic distance between four incipient species of the mole rat *Spalax ehrenbergi* is 0.022, and between those of the gopher *Thomomys talpoides* it is 0.078. The second stage of speciation is modulated in essentially the same way as in the geographic mode. Not many gene changes are needed in either case to complete speciation.

Patterns and rates of species evolution

EVOLUTION WITHIN A LINEAGE AND BY LINEAGE SPLITTING

Evolution can take place by anagenesis, in which changes occur within a lineage, or by cladogenesis, in which a lineage splits into two or more separate lines. Anagenetic evolution has doubled the size of the human cranium over the course of two million years; in the lineage of the horse it has reduced the number of toes from four to one. Cladogenetic evolution has produced the extraordinary diversity of the living world, with its more than two million species of animals, plants, fungi, and microorganisms.

The most essential cladogenetic function is speciation, the process by which one species splits into two or more species. Because species are reproductively isolated from one another, they are independent evolutionary units; that is, evolutionary changes occurring in one species are not shared with other species. Over time, species diverge more and more from one another as a consequence of anagenetic evolution. Descendant lineages of two related species that existed millions of years ago may now be classified into quite different biological categories, such as different genera or even different families.

Phylogenetic trees

The evolution of all living organisms, or of a subset of them, can be seen as a tree, with branches that divide into two or more as time progresses. Such trees are called phylogenies. Their branches represent evolving lineages, some of which eventually die out while others persist in themselves or in their derived lineages down to the present time. Evolutionists are interested in the history of life and hence in the topology, or configuration, of phylogenies. They are concerned as well with the nature of the anagenetic changes within lineages and with the timing of the events.

Phylogenetic relationships are ascertained by means of several complementary sources of evidence. First, there are the discovered remnants of organisms that lived in the past, the fossil record, which provides definitive evidence of relationships between some groups of organisms. The fossil record, however, is far from complete and is often seriously deficient. Second, information about phylogeny comes from comparative studies of living forms. Comparative anatomy contributed the most information in the past, although additional knowledge came from comparative embryology, cytology, ethology, biogeography, and other biological disciplines. In recent years the comparative study of the so-called informational macromolecules—proteins and nucleic acids, whose specific sequences of constituents carry genetic information—has become a powerful tool for the study of phylogeny (see below *Reconstruction of evolutionary history: DNA and protein as informational macromolecules*).

Morphological similarities between organisms have probably always been recognized. In ancient Greece Aristotle and later his followers and those of Plato, particularly Porphyry, classified organisms (as well as inanimate objects) on the basis of similarities. The Aristotelian system of classification was further developed by some medieval Scholastic philosophers, notably Albertus Magnus and Thomas Aquinas. The modern foundations of biological taxonomy, the science of classification of living and extinct organisms, were laid in the 18th century by the Swedish botanist Carolus Linnaeus and the French botanist Michel Adanson. The French naturalist Jean-Baptiste Lamarck dedicated much of his work to the systematic classification of organisms. He proposed that their similarities were due to ancestral relationships—in other words, to the degree of evolutionary proximity.

The modern theory of evolution provides a causal explanation of the similarities between living things. Organisms evolve by a process of descent with modification. Changes, and therefore differences, gradually accumulate over the generations. The more recent the last common ancestor of a group of organisms, the less their differentiation; similarities of form and function reflect phylogenetic propinquity. Accordingly, phylogenetic affinities can be inferred on the basis of relative similarity.

CONVERGENT AND PARALLEL EVOLUTION

Homologous and analogous correspondence of features

A distinction has to be made between resemblances due to propinquity of descent and those due only to similarity of function. As discussed above in the section *The evidence for evolution: Structural similarities,* correspondence of features in different organisms that is due to inheritance from a common ancestor is called homology. The forelimbs of humans, whales, dogs, and bats are homologous. The skeletons of these limbs are all constructed of bones arranged according to the same pattern because they derive from a common ancestor with similarly arranged forelimbs. Correspondence of features due to similarity of function but not related to common descent is termed analogy. The wings of birds and of flies are analogous. Their wings are not modified versions of a structure present in a common ancestor but rather have developed independently as adaptations to a common function, flying. The similarities between the wings of bats and birds are partially homologous and partially analogous. Their skeletal structure is homologous, owing to common descent from the forelimb of a reptilian ancestor; but the modifications for flying are different and independently evolved, and in this respect they are analogous.

Features that become more rather than less similar through independent evolution are said to be convergent. Convergence is often associated with similarity of function, as in the evolution of wings in birds, bats, and flies. The shark (a fish) and the dolphin (a mammal) are much alike in external morphology; their similarities are due to convergence, since they have evolved independently as adaptations to aquatic life.

Taxonomists also speak of parallel evolution. Parallelism and convergence are not always clearly distinguishable. Strictly speaking, convergent evolution occurs when descendants resemble each other more than their ancestors did with respect to some feature. Parallel evolution implies that two or more lineages have changed in similar ways, so that the evolved descendants are as similar to each other as their ancestors were. The evolution of marsupials in Australia, for example, paralleled the evolution of placental mammals in other parts of the world (Figure 10). There are Australian marsupials resembling true wolves, cats, mice, squirrels, moles, groundhogs, and anteaters. These placental mammals and the corresponding Australian marsupials evolved independently but in parallel lines by reason of their adaptation to similar ways of life. Some resemblances between a true anteater (genus *Myrmecophaga*) and a marsupial anteater, or numbat (*Myrmecobius*), are due to homology—both are mammals. Others are due to analogy—both feed on ants.

Parallel and convergent evolution are also common in plants. New World cacti and African euphorbias, or spurges, are alike in overall appearance although they belong to separate families. Both are succulent, spiny, water-storing plants adapted to the arid conditions of the desert. Their corresponding morphologies have evolved independently in response to similar environmental challenges.

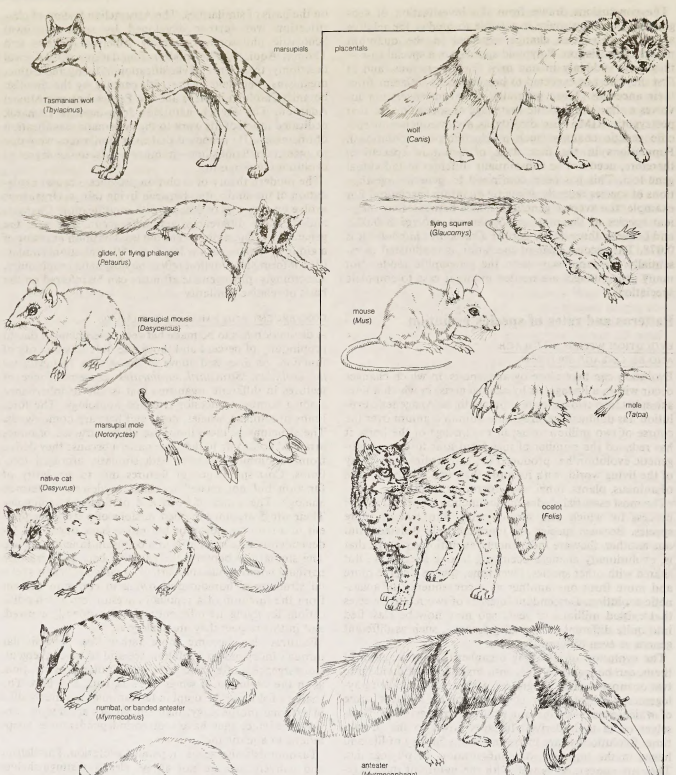

Figure 10: Parallel evolution of marsupial mammals in Australia and placental mammals on other continents.

Serial homology

Homology can be recognized not only between different organisms but also between repetitive structures of the same organism. This has been called serial homology. There is serial homology, for example, between the arms and legs of humans, between the seven cervical vertebrae of mammals, and between the branches or leaves of a tree. The jointed appendages of arthropods are elaborate examples of serial homology. Crayfish have 19 pairs of appendages, all built according to the same basic pattern but serving diverse functions—sensing, chewing, food handling, walking, mating, egg carrying, and swimming. Although serial homologies are not useful in reconstructing the phylogenetic relationships of organisms, they are an important dimension of the evolutionary process.

Relationships in some sense akin to those between serial homologs exist at the molecular level between genes and proteins derived from ancestral gene duplications. The genes coding for the various hemoglobin chains are an example. About 500 million years ago a chromosome segment carrying the gene coding for hemoglobin became duplicated, so that the genes in the different segments thereafter evolved in somewhat different ways, one eventually giving rise to the modern gene coding for the α hemoglobin chain, the other for the β chain. The β chain

gene became duplicated again about 200 million years ago, giving rise to the γ hemoglobin chain, a normal component of fetal hemoglobin (hemoblobin F). The genes for the α, β, γ, and other hemoglobin chains are homologous; similarities in their nucleotide sequences occur because they are modified descendants of a single ancestral sequence.

There are two ways of comparing homology between hemoglobins. One is to compare the same hemoglobin chain—for instance, the α chain—in different species of animals. The degree of divergence between the α chains reflects the degree of the evolutionary relationship between the organisms, because the hemoglobin chains have evolved independently of one another since the time of divergence of the lineages leading to the present-day organisms. A second way is to make comparisons between, say, the α and β chains of a single species. The degree of divergence between the different globin chains reflects the degree of relationship between the genes coding for them. The different globins have evolved independently of each other since the time of duplication of their ancestral genes. Comparisons between homologous genes or proteins within a given organism provide information about the phylogenetic history of the genes and hence about the historical sequence of the gene duplication events.

Whether similar features in different organisms are homologous or analogous—or simply accidental—cannot always be decided unambiguously, but the distinction must be made in order to determine phylogenetic relationships. Moreover, the degrees of homology must be quantified in some way so as to determine the propinquity of common descent between species. Difficulties arise here as well. In the case of forelimbs, it is not clear whether the homologies are greater between human and bird than between human and reptile, or between human and reptile than between human and bat. The fossil record sometimes provides the appropriate information, even though the record is deficient. Fossil evidence must be examined together with the evidence from comparative studies of living forms and with the quantitative estimates provided by comparative studies of proteins and nucleic acids.

GRADUAL AND PUNCTUATIONAL EVOLUTION

Discontinuities in the fossil record

The fossil record indicates that morphological evolution is by and large a gradual process. Major evolutionary changes are usually due to a building-up over the ages of relatively small changes. But the fossil record is discontinuous. Fossil strata are separated by sharp boundaries; accumulation of fossils within a geologic deposit (stratum) is fairly constant over time, but the transition from one stratum to another may involve gaps of tens of thousands of years. Whereas the fossils within a stratum exhibit little morphological variation, new species—characterized by small but discontinuous morphological changes—typically appear at the boundaries between strata. That is not to say that the transition from one stratum to another always involves sudden changes in morphology; on the contrary, fossil forms often persist virtually unchanged through several geologic strata, each representing millions of years.

The apparent morphological discontinuities of the fossil record are often attributed by paleontologists to the discontinuity of the sediments—that is, to the substantial time gaps encompassed in the boundaries between strata. The assumption is that, if the fossil deposits were more continuous, they would show a more gradual transition of form. Even so, morphological evolution would not always keep progressing gradually, because some forms, at least, remain unchanged for extremely long times. Examples are the lineages known as "living fossils"—for instance, the lamp shell *Lingula*, a genus of brachiopod (a phylum of shelled invertebrates) that appears to have remained essentially unchanged since the Ordovician Period, some 450 million years ago; or the tuatara (*Sphenodon punctatus*), a reptile that has shown little morphological evolution for nearly 200 million years, since the early Mesozoic.

Some paleontologists have proposed that the discontinuities of the fossil record are not artifacts created by gaps in the record but rather reflect the true nature of morphological evolution, which happens in sudden bursts associated with the formation of new species. The lack of morphological evolution, or stasis, of lineages such as *Lingula* and *Sphenodon* is in turn due to lack of speciation within those lineages. The proposition that morphological evolution is jerky, with most morphological change occurring during the brief speciation events and virtually no change during the subsequent existence of the species, is known as the punctuated equilibrium model.

Whether morphological evolution in the fossil record is predominantly punctuational or gradual is a much-debated question. The imperfection of the record makes it unlikely that the issue will be settled in the foreseeable future. Intensive study of a favourable and abundant set of fossils may be expected to substantiate punctuated or gradual evolution in particular cases. But the argument is not about whether only one or the other pattern ever occurs; it is about their relative frequency. Some paleontologists argue that morphological evolution is in most cases gradual and only rarely jerky, whereas others think the opposite is true.

Problem of interpretation

Much of the problem is that gradualness or jerkiness is in the eye of the beholder. Consider the evolution of shell rib strength (the ratio of rib height to rib width) within a lineage of fossil brachiopods of the genus *Eocelia*. Results of the analysis of an abundant sample of fossils in Wales from near the beginning of the Devonian Period is shown in Figure 11. One possible interpretation of the data is that rib strength changed little or not at all from 415 million to 413 million years ago; rapid change ensued for the next 1 million years, followed by virtual stasis from 412 million to 407 million years ago; and then another short burst of change occurred around 406 million years ago, followed by

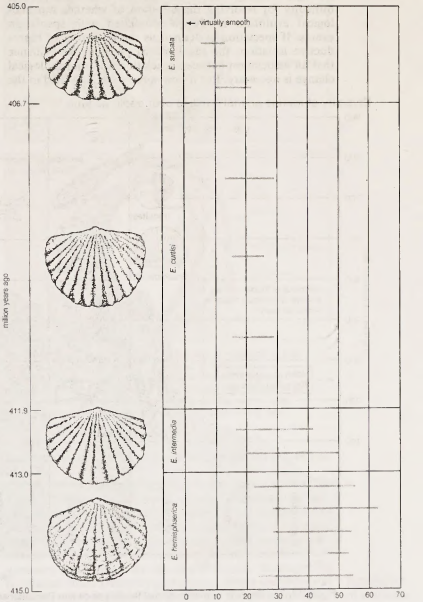

Figure 11: Rib strength in the evolution of the brachiopod *Eocelia*. The horizontal bars indicate the observed range of rib strength among fossilized finds.

a final period of stasis. On the other hand, the same record may be interpreted as not particularly punctuated but rather as a gradual process, with the rate of change somewhat greater at particular times.

The proponents of the punctuated equilibrium model propose not only that morphological evolution is jerky but also that it is associated with speciation events. They argue that phyletic evolution—that is, evolution along lineages of descent—proceeds at two levels. First, there is continuous change through time within a population. This consists largely of gene substitutions prompted by natural selection, mutation, genetic drift, and other genetic processes that operate at the level of the individual organism. The punctualists maintain that this continuous evolution within established lineages rarely, if ever, yields substantial morphological changes in species. Second, they say, there is the process of origination and extinction of species, in which most morphological change occurs. According to the punctualist model, evolutionary trends result from the patterns of origination and extinction of species rather than from evolution within established lineages.

Speciation and morphological change

As discussed above in the section *Species and speciation: The origin of species,* speciation involves the development of reproductive isolation between populations previously able to interbreed. Paleontologists discriminate between species by their different morphologies as preserved in the fossil record, but fossils cannot provide evidence of the development of reproductive isolation—new species that are reproductively isolated from their ancestors are often morphologically indistinguishable from them. Speciation as it is seen by paleontologists always involves substantial morphological change. This situation creates an insuperable difficulty for resolving the question of whether morphological evolution is always associated with speciation events. If speciation is defined as the evolution of reproductive isolation, the fossil record provides no evidence that an association between speciation and morphological change is necessary. But if new species are identified in the fossil record by morphological changes, then all such changes will occur concomitantly with the origination of new species.

DIVERSITY AND EXTINCTION

The current diversity of life is the balance between the species that have arisen through time and those that have become extinct. Paleontologists observe that organisms have continuously changed since the Cambrian Period, more than 500 million years ago, from which abundant animal fossil remains are known. The division of geologic history into a succession of eras and periods (Figure 1) is hallmarked by major changes in plant and animal life—the appearance of new sorts of organisms and the extinction of others. Paleontologists distinguish between background extinction, the steady rate at which species disappear through geologic time, and mass extinctions, episodic events in which large numbers of species become extinct over time spans short enough to appear almost instantaneous on the geologic scale.

Cretaceous mass extinction

Best known among mass extinctions is the one that occurred at the end of the Cretaceous Period, when the dinosaurs and many other marine and land animals disappeared. Most scientists believe that the Cretaceous mass extinction was provoked by the impact of an asteroid or comet on the tip of the Yucatán Peninsula in southeastern Mexico about 65 million years ago. The object's impact caused an enormous dust cloud, which greatly reduced the Sun's radiation reaching Earth, with a consequent drastic drop in temperature and other adverse conditions. Among animals, about 76 percent of species, 47 percent of genera, and 16 percent of families became extinct. Although the dinosaurs vanished, turtles, snakes, lizards, crocodiles, and other reptiles, as well as some mammals and birds, survived. Mammals that lived prior to the event were small and mostly nocturnal, but during the ensuing Tertiary Period they experienced an explosive diversification in size and morphology, occupying ecologi-

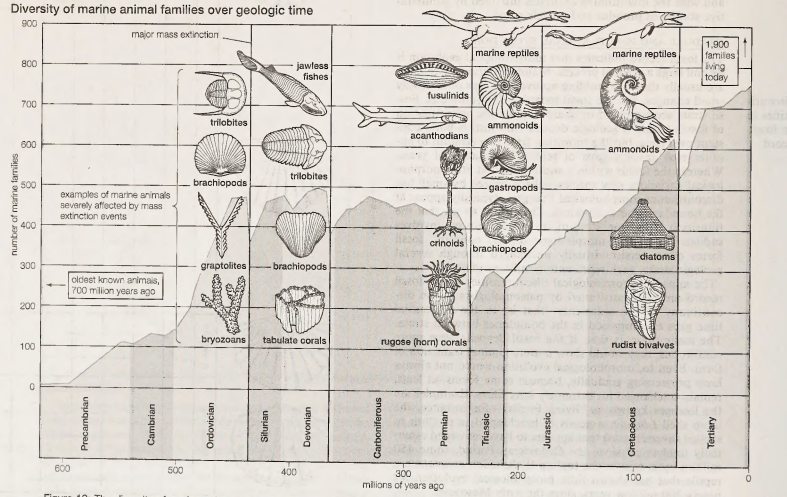

Figure 12: The diversity of marine animal families since late Precambrian time. The data for the curve comprises only those families that are reliably preserved in the fossil record; the 1,900 value for the number of families living today also includes those families rarely preserved as fossils. The several pronounced dips in the curve correspond to major mass extinction events. The most catastrophic extinction took place at the end of the Permian Period, about 245 million years ago.

cal niches vacated by the dinosaurs. Most of the orders and families of mammals now in existence originated in the first 10 million–20 million years after the dinosaurs' extinction. Birds also greatly diversified at that time.

Several other mass extinctions have occurred since the Cambrian. The most catastrophic happened at the end of the Permian Period, about 245 million years ago, when 95 percent of species, 82 percent of genera, and 51 percent of families of animals became extinct. Other large mass extinctions occurred at or near the end of the Ordovician (about 440 million years ago, 85 percent of species extinct), Devonian (about 360 million years ago, 83 percent of species extinct), and Triassic (about 210 million years ago, 80 percent of species extinct). (See Figure 12.) Changes of climate and chemical composition of the atmosphere appear to have caused these mass extinctions; there is no convincing evidence that they resulted from cosmic impacts. Like other mass extinctions, they were followed by the origin or rapid diversification of various kinds of organisms. The first mammals and dinosaurs appeared after the late Permian extinction, and the first vascular plants after the Late Ordovician extinction.

Background extinctions result from ordinary biological processes, such as competition between species, predation, and parasitism. When two species compete for very similar resources—say, the same kinds of seeds or fruits—one may become extinct, although often they will displace one another by dividing the territory or by specializing in slightly different foods, such as seeds of a different size or kind. Ordinary physical and climatic changes also account for background extinctions—for example, when a lake dries out or a mountain range rises or erodes.

Changes and advancements of function

New species come about by the processes discussed in previous sections. These processes are largely gradual, yet the history of life shows major transitions in which one kind of organism becomes a very different kind. The earliest organisms were prokaryotes, or bacteria-like cells, whose hereditary material is not segregated into a nucleus. Eukaryotes have their DNA organized into chromosomes that are membrane-bound in the nucleus, have other organelles inside their cells, and reproduce sexually. Eventually, eukaryotic multicellular organisms appeared, in which there is a division of function among cells—some specializing in reproduction, others becoming leaves, trunks, and roots in plants or different organs and tissues such as muscle, nerve, and bone in animals. Social organization of individuals in a population is another way of achieving functional division, which may be quite fixed, as in ants and bees, or more flexible, as in cattle herds or primate groups.

Because of the gradualness of evolution, immediate descendants differ little, and then mostly quantitatively, from their ancestors. But gradual evolution may amount to large differences over time. The forelimbs of mammals are normally adapted for walking, but they are adapted for shoveling earth in moles and other mammals that live mostly underground, for climbing and grasping in arboreal monkeys and apes, for swimming in dolphins and whales, and for flying in bats. The forelimbs of reptiles became wings in their bird descendants. Feathers appear to have served first for regulating temperature but eventually were coopted for flying and became incorporated into wings.

Eyes, which serve as another example, also evolved gradually and achieved very different configurations, all serving the function of seeing. Eyes have evolved independently at least 40 times. Because sunlight is a pervasive feature of Earth's environment, it is not surprising that organs have evolved that take advantage of it. The simplest "organ" of vision occurs in some single-celled organisms that have enzymes or spots sensitive to light, which helps them move toward the surface of their pond, where they feed on the algae growing there by photosynthesis. Some multicellular animals exhibit light-sensitive spots on their epidermis. Further steps—deposition of pigment around the spot, configuration of cells into a cuplike shape, thickening of the epidermis leading to the development of a lens, development of muscles to move the eyes and nerves to transmit optical signals to the brain—all led to the highly developed eyes of vertebrates and cephalopods (octopuses and squids) and to the compound eyes of insects (see Figure 13).

Stages of eye complexity in mollusks

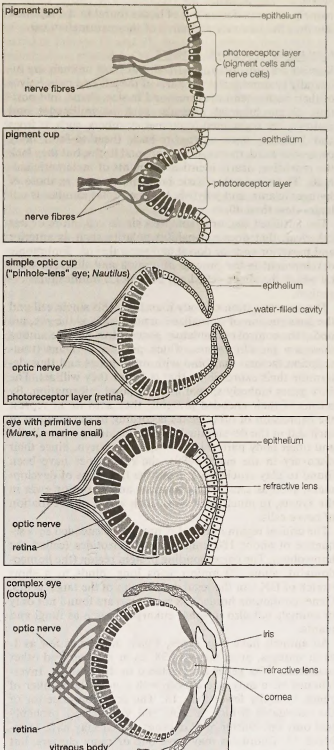

Figure 13: Steps in the evolution of the eye as reflected in the range of eye complexity in living mollusk species (top to bottom): a pigment spot, as in the limpet *Patella*; a pigment cup, as in the slit shell mollusk *Pleurotomaria*; the "pinhole-lens" eye of *Nautilus*; a primitive lensed eye, as in the marine snail *Murex*; and the complex eye—with iris, crystalline lens, and retina—of octopuses and squids.

While the evolution of forelimbs—for walking—into the wings of birds or the arms and hands of primates may seem more like changes of function, the evolution of eyes exemplifies gradual advancement of the same function—seeing. In all cases, however, the process is impelled by natural selection's favouring individuals exhibiting functional advantages over others of the same species. Examples of functional shifts are many and diverse. Some transitions at first may seem unlikely because of the difficulty in identifying which possible functions may have been served during the intermediate stages. These cases are eventually resolved with further research and the discovery of intermediate fossil forms. An example of a seemingly unlikely

Resolution of seemingly unlikely transitions

transition is described above in the section *General overview: The evidence for evolution: The fossil record*—namely, the transformation of bones found in the reptilian jaw into the hammer and anvil of the mammalian ear.

EVOLUTION AND DEVELOPMENT

Starfish are radially symmetrical, but most animals are bilaterally symmetrical—the parts of the left and right halves of their bodies tend to correspond in size, shape, and position. Some bilateral animals, such as millipedes and shrimps, are segmented (metameric); others, such as frogs and humans, have a front-to-back (head-to-foot) body plan, with head, thorax, abdomen, and limbs, but they lack the repetitive, nearly identical segments of metameric animals. There are other basic body plans, such as those of sponges, clams, and jellyfish, but their total number is not large—less than 40.

The fertilized egg, or zygote, is a single cell, more or less spherical, that does not exhibit polarity such as anterior and posterior ends or dorsal and ventral sides. Embryonic development is the process of growth and differentiation by which the single-celled egg becomes a multicellular organism.

Action of regulatory genes

The determination of body plan from this single cell and the construction of specialized organs, such as the eye, are under the control of regulatory genes. Most notable among these are the *Hox* genes, which produce proteins (transcription factors) that bind with other genes and thus determine their expression—that is, when they will act. The *Hox* genes embody spatial and temporal information. By means of their encoded proteins, they activate or repress the expression of other genes according to the position of each cell in the developing body, determining where limbs and other body parts will grow in the embryo. Since their discovery in the early 1980s, the *Hox* genes have been found to play crucial roles from the first steps of development, such as establishing anterior and posterior ends in the zygote, to much later steps, such as the differentiation of nerve cells.

The critical region of the *Hox* proteins is encoded by a sequence of about 180 consecutive nucleotides (called the homeobox). The corresponding protein region (the homeodomain), about 60 amino acids long, binds to a short stretch of DNA in the regulatory region of the target genes. Genes containing homeobox sequences are found not only in animals but also in other eukaryotes such as fungi and plants.

All animals have *Hox* genes, which may be as few as 1, as in sponges, or as many as 38, as in humans and other mammals. *Hox* genes are clustered in the genome. Invertebrates have only one cluster with a variable number of genes, typically fewer than 13. The common ancestor of the chordates (which include the vertebrates) probably had only one cluster of *Hox* genes, which may have numbered 13. Chordates may have one or more clusters, but not all 13 genes remain in every cluster. The marine animal amphioxus, a primitive chordate, has a single array of 10 *Hox* genes. Humans, mice, and other mammals have 38 *Hox* genes arranged in four clusters, three with 9 genes each and one with 11 genes. The set of genes varies from cluster to cluster, so that out of the 13 in the original cluster, genes designated 1, 2, 3, and 7 may be missing in one set, whereas 10, 11, 12, and 13 may be missing in a different set.

The four clusters of *Hox* genes found in mammals originated by duplication of the whole original cluster and retain considerable similarity between clusters. The 13 genes in the original cluster also themselves originated by repeated duplication, starting from a single *Hox* gene as found in the sponges. These first duplications happened very early in animal evolution, in the Precambrian. The genes within a cluster retain detectable similarity, but they differ more from one another than they differ from the corresponding, or homologous, gene in any of the other sets. There is a puzzling correspondence between the position of the *Hox* genes in a cluster along the chromosome and the patterning of the body—genes located upstream (anteriorly in the direction in which genes are transcribed) in the cluster are expressed earlier and more anteriorly in the body, while those located downstream (posteriorly in the direction of transcription) are expressed later in development and predominantly impact the posterior body parts.

Evolutionary conservation of the *Hox* genes

Researchers demonstrated the evolutionary conservation of the *Hox* genes by means of clever manipulations of genes in laboratory experiments. For example, the *ey* gene that determines the formation of the compound eye in *Drosophila* vinegar flies was activated in the developing embryo in various parts of the body, yielding experimental flies with anatomically normal eyes on the legs, wings, and other structures. The evolutionary conservation of the *Hox* genes may be the explanation for the puzzling observation that most of the diversity of body plans within major groups of animals arose early in the evolution of the group. The multicellular animals (metazoans) first found as fossils in the Cambrian already demonstrate all the major body plans found during the ensuing 540 million years, as well as four to seven additional body plans that became extinct and seem bizarre to observers today. Similarly, most of the classes found within a phylum appear early in the evolution of the phylum. For example, all living classes of arthropods are already found in the Cambrian, with body plans essentially unchanged thereafter; in addition, the Cambrian contains a few strange kinds of arthropods that later became extinct.

Reconstruction of evolutionary history

DNA AND PROTEIN AS INFORMATIONAL MACROMOLECULES

The advances of molecular biology have made possible the comparative study of proteins and the nucleic acids, DNA and RNA. DNA is the repository of hereditary (evolutionary and developmental) information. The relationship of proteins to DNA is so immediate that they closely reflect the hereditary information. This reflection is not perfect, because the genetic code is redundant, and, consequently, some differences in the DNA do not yield differences in the proteins. Moreover, this reflection is not complete, because a large fraction of DNA (about 90 percent in many organisms) does not code for proteins. Nevertheless, proteins are so closely related to the information contained in DNA that they, as well as nucleic acids, are called informational macromolecules.

Nucleic acids and proteins are linear molecules made up of sequences of units—nucleotides in the case of nucleic acids, amino acids in the case of proteins—which retain considerable amounts of evolutionary information. Comparing two macromolecules establishes the number of their units that are different. Because evolution usually occurs by changing one unit at a time, the number of differences is an indication of the recency of common ancestry. Changes in evolutionary rates may create difficulties in interpretation, but macromolecular studies have three notable advantages over comparative anatomy and the other classical disciplines. One is that the information is more readily quantifiable. The number of units that are different is readily established when the sequence of units is known for a given macromolecule in different organisms. The second advantage is that comparisons can be made even between very different sorts of organisms. There is very little that comparative anatomy can say when organisms as diverse as yeasts, pine trees, and human beings are compared, but there are homologous macromolecules that can be compared in all three. The third advantage is multiplicity. Each organism possesses thousands of genes and proteins, which all reflect the same evolutionary history. If the investigation of one particular gene or protein does not resolve the evolutionary relationship of a set of species, additional genes and proteins can be investigated until the matter has been settled.

Advantages of macromolecular studies

Informational macromolecules provide information not only about the branching of lineages from common ancestors (cladogenesis) but also about the amount of genetic change that has occurred in any given lineage (anagenesis). It might seem at first that quantifying anagenesis for proteins and nucleic acids would be impossible, because it would require comparison of molecules from organisms

that lived in the past with those from living organisms. Organisms of the past are sometimes preserved as fossils, but their DNA and proteins have largely disintegrated. Nevertheless, comparisons between living species provide information about anagenesis.

The following is an example of such comparison: Two living species, C and D, have a common ancestor, the extinct species B (see Figure 14). If C and D were found to differ

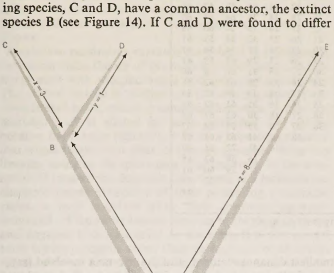

Figure 14: Amount of change in the evolutionary history of three living species (C, D, and E), inferred by comparing amino-acid differences in their myoglobin molecules.

by four amino-acid substitutions in a single protein, then it could tentatively be assumed that two substitutions (four total changes divided by two species) had taken place in the evolutionary lineage of each species. This assumption, however, could be invalidated by the discovery of a third living species, E, that is related to C, D, and their ancestor, B, through an earlier ancestor, A. The number of amino-acid differences between the protein molecules of the three living species may be as follows:

C and D = 4
C and E = 11
D and E = 9

Figure 14 proposes a phylogeny of the three living species, making it possible to estimate the number of amino-acid substitutions that have occurred in each lineage. Let x denote the number of differences between B and C, y denote the differences between B and D, and z denote the differences between A and B as well as A and E. The following three equations can be produced:

$$x + y = 4$$
$$x + z = 11$$
$$y + z = 9$$

Solving the equations yields $x = 3$, $y = 1$, and $z = 8$.

Phylogenetic information from cytochrome c

As a concrete example, consider the protein cytochrome c, involved in cell respiration. The sequence of amino acids in this protein is known for many organisms, from bacteria and yeasts to insects and humans; in animals cytochrome c consists of 104 amino acids. When the amino-acid sequences of humans and rhesus monkeys are compared, they are found to be different at position 66 (isoleucine in humans, threonine in rhesus monkeys) but identical at the other 103 positions. When humans are compared with horses, 12 amino-acid differences are found, but when horses are compared with rhesus monkeys, there are only 11 amino-acid differences. Even without knowing anything else about the evolutionary history of mammals, one would conclude that the lineages of humans and rhesus monkeys diverged from each other much more recently than they diverged from the horse lineage. Moreover, it can be concluded that the amino-acid difference between humans and rhesus monkeys must have occurred in the human lineage after its separation from the rhesus monkey lineage (see Figure 15).

EVOLUTIONARY TREES

Evolutionary trees are models that seek to reconstruct the evolutionary history of taxa—*i.e.*, species or other groups of organisms, such as genera, families, or orders. As illustrated in Figures 14 and 15, the trees embrace two kinds of information related to evolutionary change, cladogenesis and anagenesis. The branching relationships reflect the relative relationships of ancestry, or cladogenesis. Thus, in Figure 15, humans and rhesus monkeys are seen to be more closely related to each other than either is to the horse. Stated another way, this tree shows that the last common ancestor to all three species lived in a more remote past than the last common ancestor to humans and monkeys.

Evolutionary trees may also indicate the changes that have occurred along each lineage, or anagenesis. Thus, in the evolution of cytochrome c since the last common ancestor of humans and rhesus monkeys (Figure 15), one amino acid changed in the lineage going to humans but none in the lineage going to rhesus monkeys. Similarly, Figure 14 shows that three amino-acid changes occurred in the lineage from B to C but only one in the lineage from B to D.

Methods of construction

There exist several methods for constructing evolutionary trees. Some were developed for interpreting morphological data, others for interpreting molecular data; some can be used with either kind of data. The main methods currently in use are called distance, parsimony, and maximum likelihood.

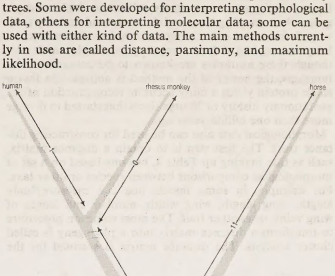

Figure 15: Phylogeny of the human, rhesus monkey, and horse, based on amino-acid substitutions in the evolution of cytochrome c in the lineages of the three species.

Distance methods. A "distance" is the number of differences between two taxa. The differences are measured with respect to certain traits (*i.e.*, morphological data) or to certain macromolecules (primarily the sequence of amino acids in proteins or the sequence of nucleotides in DNA or RNA). The trees illustrated in Figures 14 and 15 were obtained by taking into account the distance, or number of amino-acid differences, between three organisms with respect to a particular protein. The amino-acid sequence of a protein contains more information than is reflected in the number of amino-acid differences. This is because in some cases the replacement of one amino acid by another requires no more than one nucleotide substitution in the DNA that codes for the protein, whereas in other cases it requires at least two nucleotide changes. Table 4 shows the minimum number of nucleotide differences in the genes of 20 separate species that are necessary to account for the amino-acid differences in their cytochrome c. An evolutionary tree based on the data in Table 4, showing the minimum numbers of nucleotide changes in each branch, is illustrated in Figure 16.

The relationships between species as shown in Figure 16 correspond fairly well to the relationships determined from other sources, such as the fossil record. According to the

Table 4: Minimum Number of Nucleotide Differences in Genes Coding for Cytochrome c in 20 Different Organisms

organism	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Human	—	1	13	17	16	13	12	12	17	16	18	18	19	20	31	33	36	63	56	66
2. Monkey			12	16	15	12	11	13	16	15	17	17	18	21	32	32	35	62	57	65
3. Dog				10	8	4	6	7	12	12	14	14	13	30	29	24	28	64	61	66
4. Horse					1	5	11	11	16	16	16	17	16	32	27	24	33	64	60	68
5. Donkey						4	10	12	15	15	15	16	15	31	26	25	32	64	59	67
6. Pig							6	7	13	13	13	14	13	30	25	26	31	64	59	67
7. Rabbit								7	10	8	11	11	11	25	26	23	29	62	59	67
8. Kangaroo									14	14	15	13	14	30	27	26	31	66	58	68
9. Duck										3	3	3	7	24	26	25	29	61	62	66
10. Pigeon											4	4	8	24	27	26	30	59	62	66
11. Chicken												2	8	28	26	26	31	61	62	66
12. Penguin													8	28	27	28	30	62	61	65
13. Turtle														30	27	30	33	65	64	67
14. Snake															38	40	41	61	61	69
15. Tuna																34	41	72	66	69
16. Screwworm																	16	58	63	65
17. Moth																		59	60	61
18. *Neurospora* (mold)																			57	61
19. *Saccharomyces* (yeast)																				41
20. *Candida* (yeast)																				—

Source: Walter M. Fitch, *Science*, vol. 155, Jan. 20, 1967, p. 281, copyright 1967 by the AAAS.

figure, chickens are less closely related to ducks and pigeons than to penguins, and humans and monkeys diverged from the other mammals before the marsupial kangaroo separated from the nonprimate placentals. Although these examples are known to be erroneous relationships, the power of the method is apparent in that a single protein yields a fairly accurate reconstruction of the evolutionary history of 20 organisms that started to diverge more than one billion years ago.

Usefulness of morphological data

Morphological data also can be used for constructing distance trees. The first step is to obtain a distance matrix, such as that making up Table 4, but one based on a set of morphological comparisons between species or other taxa. For example, in some insects one can measure body length, wing length, wing width, number and length of wing veins, or another trait. The most common procedure to transform a distance matrix into a phylogeny is called cluster analysis. The distance matrix is scanned for the smallest distance element, and the two taxa involved (say, A and B) are joined at an internal node, or branching point. The matrix is scanned again for the next smallest distance, and the two new taxa (say, C and D) are clustered. The procedure is continued until all taxa have been joined. When a distance involves a taxon that is already part of a previous cluster (say, E and A), the average distance is obtained between the new taxon and the preexisting cluster (say, the average distance between E to A and E to B). This simple procedure, which can also be used with molecular data, assumes that the rate of evolution is uniform along all branches.

Other distance methods (including the one used to construct the tree in Figure 16) relax the condition of uniform rate and allow for unequal rates of evolution along the branches. One of the most extensively used methods of this kind is called neighbour-joining. The method starts, as before, by identifying the smallest distance in the matrix and linking the two taxa involved. The next step is to remove these two taxa and calculate a new matrix in which their distances to other taxa are replaced by the distance between the node linking the two taxa and all other taxa. The smallest distance in this new matrix is used for making the next connection, which will be between two other taxa or between the previous node and a new taxon. The procedure is repeated until all taxa have been connected with one another by intervening nodes.

Neighbour-joining method

Maximum parsimony methods. Maximum parsimony methods seek to reconstruct the tree that requires the fewest (*i.e.*, most parsimonious) number of changes summed along all branches. This is a reasonable assumption, because it usually will be the most likely. But evolution may not necessarily have occurred following a minimum path, because the same change instead may have occurred independently along different branches, and some changes may have involved intermediate steps. Consider three species—C, D, and E. If C and D differ by two amino acids in a certain protein and either one differs by three amino acids from E, parsimony will lead to a tree with the structure shown in Figure 14. It may be the case, however, that in a certain position at which C and D both have amino acid g while E has h, the ancestral amino acid was g. Amino acid g did not change in the lineage going to C but changed to h in a lineage going to the ancestor of D and E and then changed again, back to g, in the lineage going to D. The correct phylogeny would lead then from the common ancestor of all three species to C in one branch (in which no amino-acid changes occurred), and to the last common ancestor of D and E in the other branch (in which g changed to h) with one additional change (from h to g) occurring in the lineage from this ancestor to E.

Not all evolutionary changes, even those that involve a single step, may be equally probable. For example, among the four nucleotide bases in DNA, cytosine (C) and thymine (T) are members of a family of related molecules

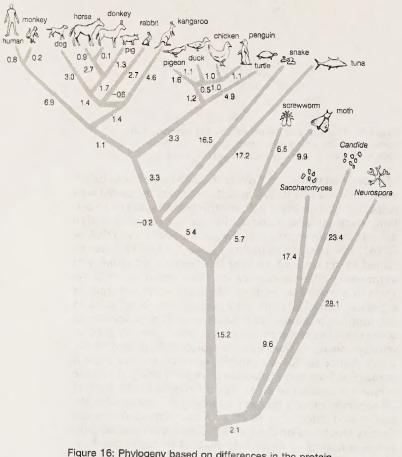

Figure 16: Phylogeny based on differences in the protein sequence of cytochrome c in organisms ranging from the mold *Neurospora* to humans. The numbers are estimates of the nucleotide substitutions that have occurred along the lineages in the gene coding for this protein.

called pyrimidines; likewise, adenine (A) and guanine (G) belong to a family of molecules called purines. A change within a DNA sequence from one pyrimidine to another (C↔T) or from one purine to another (A↔G), called a transition, is more likely to occur than a change from a purine to a pyrimidine or the converse (G or A↔C or T), called a transversion. Parsimony methods take into account different probabilities of occurrence if they are known.

Relationship to cladistics

Maximum parsimony methods are related to cladistics, a very formalistic theory of taxonomic classification, extensively used with morphological and paleontological data. The critical feature in cladistics is the identification of derived shared traits, called synapomorphic traits. A synapomorphic trait is shared by some taxa but not others because the former inherited it from a common ancestor that acquired the trait after its lineage separated from the lineages going to the other taxa. For example, in the evolution of carnivores, domestic cats, tigers, and leopards are clustered together because of their possessing retractable claws, a trait acquired after their common ancestor branched off from the lineage leading to the dogs, wolves, and coyotes. It is important to ascertain that the shared traits are homologous rather than analogous. For example, mammals and birds, but not lizards, have a four-chambered heart. Yet birds are more closely related to lizards than to mammals; the four-chambered heart evolved independently in the bird and mammal lineages, by parallel evolution.

Maximum likelihood methods. Maximum likelihood methods seek to identify the most likely tree, given the available data. They require that an evolutionary model be identified, which would make it possible to estimate the probability of each possible individual change. For example, as is mentioned in the preceding section, transitions are more likely than transversions among DNA nucleotides, but a particular probability must be assigned to each. All possible trees are considered. The probabilities for each individual change are multiplied for each tree. The best tree is the one with the highest probability (or maximum likelihood) among all possible trees.

Maximum likelihood methods are computationally expensive when the number of taxa is large, because the number of possible trees (for each of which the probability must be calculated) grows factorially with the number of taxa. With 10 taxa, there are about 3.6 million possible trees; with 20 taxa, the number of possible trees is about 2 followed by 18 zeroes (2×10^{18}). Even with powerful computers, maximum likelihood methods can be prohibitive if the number of taxa is large. Heuristic methods exist in which only a subsample of all possible trees is examined and thus an exhaustive search is avoided.

Evaluation of evolutionary trees. The statistical degree of confidence of a tree can be estimated for distance and maximum likelihood trees. The most common method is called bootstrapping. It consists of taking samples of the data by removing at least one data point at random and then constructing a tree for the new data set. This random sampling process is repeated hundreds or thousands of times. The bootstrap value for each node is defined by the percentage of cases in which all species derived from that node appear together in the trees. Bootstrap values above 90 percent are regarded as statistically strongly reliable; those below 70 percent are considered unreliable.

Molecular evolution

MOLECULAR PHYLOGENY OF GENES

The methods for obtaining the nucleotide sequences of DNA have enormously improved since the 1980s and have become largely automated. Many genes have been sequenced in numerous organisms, and the complete genome has been sequenced in various species ranging from humans to viruses. The use of DNA sequences has been particularly rewarding in the study of gene duplications. The genes that code for the hemoglobins in humans and other mammals provide a good example.

Knowledge of the amino-acid sequences of the hemoglobin chains and of myoglobin, a closely related protein, has made it possible to reconstruct the evolutionary history of the duplications that gave rise to the corresponding genes. But direct examination of the nucleotide sequences in the genes coding for these proteins has shown that the situation is more complex, and also more interesting, than it appears from the protein sequences.

Evolutionary history of the globin genes

DNA sequence studies on human hemoglobin genes have shown that their number is greater than previously thought. Hemoglobin molecules are tetramers (molecules made of four subunits), consisting of two polypeptides (relatively short protein chains) of one kind and two of another kind. In embryonic hemoglobin E one of the two kinds of polypeptide is designated ε; in fetal hemoglogin F it is γ; in adult hemoglobin A it is β and in adult hemoglobin A_2 it is δ. (Hemoglobin A makes up about 98 percent of human adult hemoglobin, and hemoglobin A_2 about 2 percent). The other kind of polypeptide in embryonic hemoglobin is ζ; in both fetal and adult hemoglobin it is α. The genes coding for the first group of polypeptides (ε, γ, β, and δ) are located on chromosome 11; the genes coding for the second group of polypeptides (ζ and α) are located on chromosome 16.

There are yet additional complexities. Two γ genes exist (known as G_γ and A_γ), as do two α genes (α_1 and α_2). Furthermore, there are two β pseudogenes ($\psi\beta_1$ and $\psi\beta_2$) and two α pseudogenes ($\psi\alpha_1$ and $\psi\alpha_2$), as well as a ζ pseudogene. These pseudogenes are very similar in nucleotide sequence to the corresponding functional genes, but they include terminating codons and other mutations that make it impossible for them to yield functional hemoglobins.

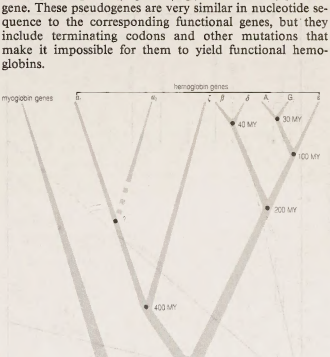

Figure 17: Evolutionary history of the globin genes. The dots indicate points at which ancestral genes duplicated, giving rise to new gene lineages. The approximate times when these duplications occurred are indicated in millions of years (MY) ago. The time when the duplication of α_1 and α_2 occurred is uncertain.

The similarity in the nucleotide sequence of the polypeptide genes, and pseudogenes, of both the α and β gene families indicates that they are all homologous—that is, that they have arisen through various duplications and subsequent evolution from a gene ancestral to all. Moreover, homology also exists between the nucleotide sequences that separate one gene from another. The evolutionary history of the genes for hemoglobin and myoglobin is summarized in Figure 17.

MULTIPLICITY AND RATE HETEROGENEITY

Cytochrome c consists of only 104 amino acids, encoded by 312 nucleotides. Nevertheless, this short protein stores

enormous evolutionary information, which made possible the fairly good approximation, shown in Figure 16, to the evolutionary history of 20 very diverse species over a period longer than one billion years. But cytochrome c is a slowly evolving protein. Widely different species have in common a large proportion of the amino acids in their cytochrome c, which makes possible the study of genetic differences between organisms only remotely related. For the same reason, however, comparing cytochrome c molecules cannot determine evolutionary relationships between closely related species. For example, the amino-acid sequence of cytochrome c in humans and chimpanzees is identical, although they diverged about 6 million years ago; between humans and rhesus monkeys, which diverged from their common ancestor 35 million to 40 million years ago, it differs by only one amino-acid replacement.

Proteins that evolve more rapidly than cytochrome c can be studied in order to establish phylogenetic relationships between closely related species. Some proteins evolve very fast; the fibrinopeptides—small proteins involved in the blood-clotting process—are suitable for reconstructing the phylogeny of recently evolved species, such as closely related mammals. Other proteins evolve at intermediate rates; the hemoglobins, for example, can be used for reconstructing evolutionary history over a fairly broad range of time (see Figure 18).

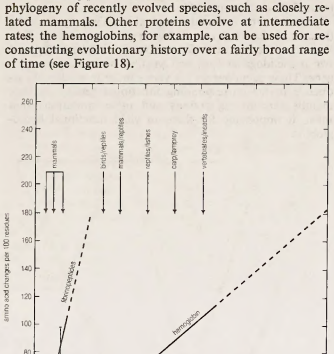

Figure 18: Three proteins with very different evolutionary rates: fibrinopeptides (very fast), hemoglobin (intermediate), and cytochrome c (slow).

Exploiting the range of evolutionary rates

One great advantage of molecular evolution is its multiplicity, as noted above in the section *Reconstruction of evolutionary history: DNA and protein as informational macromolecules*. Within each organism are thousands of genes and proteins; these evolve at different rates, but every one of them reflects the same evolutionary events. Scientists can obtain greater and greater accuracy in reconstructing the evolutionary phylogeny of any group of organisms by increasing the number of genes investigated. The range of differences in the rates of evolution between genes opens up the opportunity of investigating different sets of genes for achieving different degrees of resolution in the tree, relying on slowly evolving ones for remote evolutionary events. Even genes that encode slowly evolving proteins can be useful for reconstructing the evolutionary relationships between closely related species, by examination of the redundant codon substitutions (nucleotide substitutions that do not change the encoded amino acids), the introns (noncoding DNA segments interspersed among the segments that code for amino acids), or other noncoding segments of the genes (such as the sequences that precede and follow the encoding portions of genes); these generally evolve much faster than the nucleotides that specify the amino acids.

THE MOLECULAR CLOCK OF EVOLUTION

One conspicuous attribute of molecular evolution is that differences between homologous molecules can readily be quantified and expressed, as, for example, proportions of nucleotides or amino acids that have changed. Rates of evolutionary change can therefore be more precisely established with respect to DNA or proteins than with respect to phenotypic traits of form and function. Studies of molecular evolution rates have led to the proposition that macromolecules may serve as evolutionary clocks.

It was first observed in the 1960s that the numbers of amino-acid differences between homologous proteins of any two given species seemed to be nearly proportional to the time of their divergence from a common ancestor. If the rate of evolution of a protein or gene were approximately the same in the evolutionary lineages leading to different species, proteins and DNA sequences would provide a molecular clock of evolution. The sequences could then be used to reconstruct not only the sequence of branching events of a phylogeny but also the time when the various events occurred.

Assumption of a constant rate of change

Consider, for example, Figure 16. If the substitution of nucleotides in the gene coding for cytochrome c occurred at a constant rate through time, one could determine the time elapsed along any branch of the phylogeny simply by examining the number of nucleotide substitutions along that branch. One would need only to calibrate the clock by reference to an outside source, such as the fossil record, that would provide the actual geologic time elapsed in at least one specific lineage.

The molecular evolutionary clock, of course, is not expected to be a metronomic clock, like a watch or other timepiece that measures time exactly, but a stochastic clock like radioactive decay. In a stochastic clock the probability of a certain amount of change is constant (for example, a given quantity of atoms of radium-226 is expected, through decay, to be reduced by half in 1,620 years), although some variation occurs in the actual amount of change. Over fairly long periods of time a stochastic clock is quite accurate. The enormous potential of the molecular evolutionary clock lies in the fact that each gene or protein is a separate clock. Each clock "ticks" at a different rate—the rate of evolution characteristic of a particular gene or protein—but each of the thousands and thousands of genes or proteins provides an independent measure of the same evolutionary events.

Evolutionists have found that the amount of variation observed in the evolution of DNA and proteins is greater than is expected from a stochastic clock—in other words, the clock is erratic. The discrepancies in evolutionary rates along different lineages are not excessively large, however. So it is possible, in principle, to time phylogenetic events with as much accuracy as may be desired, but more genes or proteins (about two to four times as many) must be examined than would be required if the clock was stochastically constant. The average rates obtained for several proteins taken together become a fairly precise clock, particularly when many species are studied and the evolutionary events involve long time periods (on the order of 50 million years or more).

Compensation for an erratic clock

This conclusion is illustrated in Figure 19, which plots the cumulative number of nucleotide changes in seven proteins against the dates of divergence of 15 species of mammals as determined from the fossil record. The overall rate of nucleotide substitution is fairly uniform. Some primate species (represented by the points below the line at the lower left of Figure 19) appear to have evolved at a slower rate than the average for the rest of the species. This anomaly occurs because the more recent the divergence of any two species, the more likely it is that the changes observed will depart from the average evolutionary rate. As the length of time increases, periods of rapid and slow evolution in any lineage are likely to cancel out.

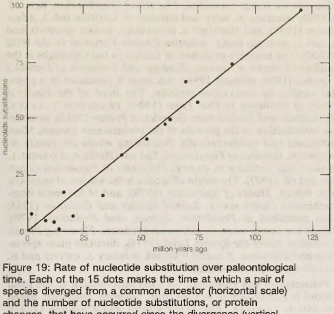

Figure 19: Rate of nucleotide substitution over paleontological time. Each of the 15 dots marks the time at which a pair of species diverged from a common ancestor (horizontal scale) and the number of nucleotide substitutions, or protein changes, that have occurred since the divergence (vertical scale). The solid line drawn from the origin to the outermost dot gives the average rate of substitution.
From F.J. Ayala, E. McMullin (ed.), *Evolution and Creation* (1985)

Evolutionists have discovered, however, that molecular time estimates tend to be systematically older than estimates based on other methods and, indeed, to be older than the actual dates. This is a consequence of the statistical properties of molecular estimates, which are asymmetrically distributed. Owing to chance, the number of molecular differences between two species may be larger or smaller than expected. But overestimation errors are unbounded, whereas underestimation errors are bounded, since they cannot be smaller than zero. Consequently, a graph of a typical distribution of estimates of the age when two species diverged, gathered from a number of different genes, is skewed from the normal bell shape, with a large number of estimates of younger age clustered together at one end and a long "tail" of older-age estimates trailing away toward the other end. The average of the estimated times thus will consistently overestimate the true date. The overestimation bias becomes greater when the rate of molecular evolution is slower, the sequences used are shorter, and the time becomes increasingly remote.

THE NEUTRALITY THEORY OF MOLECULAR EVOLUTION

In the late 1960s it was proposed that at the molecular level most evolutionary changes are selectively "neutral," meaning that they are due to genetic drift rather than to natural selection. Nucleotide and amino-acid substitutions appear in a population by mutation. If alternative alleles (alternative DNA sequences) have identical fitness—if they are identically able to perform their function—changes in allelic frequency from generation to generation will occur only by genetic drift. Rates of allelic substitution will be stochastically constant—that is, they will occur with a constant probability for a given gene or protein. This constant rate is the mutation rate for neutral alleles.

According to the neutrality theory, a large proportion of all possible mutants at any gene locus are harmful to their carriers. These mutants are eliminated by natural selection, just as standard evolutionary theory postulates. The neutrality theory also agrees that morphological, behavioral, and ecological traits evolve under the control of natural selection. What is distinctive in the theory is the claim that at each gene locus there are several favourable mutants, equivalent to one another with respect to adaptation, so that they are not subject to natural selection among themselves. Which of these mutants increases or decreases in frequency in one or another species is purely a matter of chance, the result of random genetic drift over time.

Genetic drift over natural selection

Neutral alleles are those that differ so little in fitness that their frequencies change by random drift rather than by natural selection. This definition is formally stated as $4N_e s < 1$, where N_e is the effective size of the population and s is the selective coefficient that measures the difference in fitness between the alleles.

Assume that k is the rate of substitution of neutral alleles per unit time in the course of evolution. The time units can be years or generations. In a random-mating population with N diploid individuals, $k = 2Nux$, where u is the neutral mutation rate per gamete per unit time (time measured in the same units as for k) and x is the probability of ultimate fixation of a neutral mutant. The derivation of this equation is straightforward: there are $2Nu$ mutants per time unit, each with a probability x of becoming fixed. In a population of N diploid individuals there are $2N$ genes at each locus, all of them, if they are neutral, with an identical probability, $x = 1/(2N)$, of becoming fixed. If this value of x is substituted in the equation above ($k = 2Nux$), the result is $k = u$. In terms of the theory, then, the rate of substitution of neutral alleles is precisely the rate at which the neutral alleles arise by mutation, independently of the number of individuals in the population or of any other factors.

If the neutrality theory of molecular evolution is strictly correct, it will provide a theoretical foundation for the hypothesis of the molecular evolutionary clock, since the rate of neutral mutation would be expected to remain constant through evolutionary time and in different lineages. The number of amino-acid or nucleotide differences between species would, therefore, simply reflect the time elapsed since they shared the last common ancestor.

Debate over the neutrality theory

Evolutionists debate whether the neutrality theory is valid. Tests of the molecular clock hypothesis indicate that the variations in the rates of molecular evolution are substantially larger than would be expected according to the neutrality theory. Other tests have revealed substantial discrepancies between the amount of genetic polymorphism found in populations of a given species and the amount predicted by the theory. But defenders of the theory argue that these discrepancies can be assimilated by modifying the theory somewhat—by assuming, for example, that alleles are not strictly neutral but their differences in selective value are quite small. Be that as it may, the neutrality theory provides a "null hypothesis," or point of departure, for measuring molecular evolution.

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